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made by Federighi (*3*) while working in the lower James River, Virginia. He reported that *U. cinerea* may be carried considerable distances by hermit crabs, *Pagurus* sp. Later, Carriker (*1*) cited similar observations made by two workers in Barnegat Bay, New Jersey. Carriker also cited a personal communication by J. R. Nelson who saw a horseshoe "crab," *Limulus polyphemus*, transporting 140 gastropods. Neither species of gastropod nor locality, however, is mentioned.

On 13 October 1961, while dredging on an oyster bed at a depth of 18 feet in New Haven Harbor, Long Island Sound, we collected nearly 50 horseshoe "crabs." These were predominantly large animals that had the eroded, dark-colored carapaces characteristic of older adults. The majority had a large number of oyster drills attached to various parts of their bodies, mostly on the dorsal side of the carapace (Fig. 1). The largest number of drills found on a single individual was 765, of which 761 were *Eupleura caudata* and only four were *Urosalpinx cinerea*. On some parts of the "crabs" the drills were so numerous that they formed three or four layers. Inspection of the carapaces showed no evidence of boring activity by the drills, nor were the drills boring each other.

Fig. 1. Horseshoe "crab," *Limulus polyphemus*, with a large number of oyster drills, *Eupleura caudata* and *Urosalpinx cinerea*, attached. The "crab" was dredged from 18 feet of water in New Haven Harbor, Long Island Sound, Connecticut.

Transportation of Oyster Drills by Horseshoe "Crabs"

Abstract. Horseshoe "crabs" (*Limulus polyphemus*) collected in New Haven Harbor, Long Island Sound, had large numbers of oyster drills attached to them. Since these animals migrate long distances, they may be important distributors of oyster drills.

Attempts to protect shellfish beds from predaceous gastropods, *Eupleura caudata* and *Urosalpinx cinerea*, by removing the predators by mechanical (*1*) or chemical (*2*) methods may be only partially effective because these gastropods can reinvade the beds. For example, benthic arthropods may carry these gastropods back into cleared areas. The first record of phoresy of oyster drills on benthic arthropods was

Originally the total number of drills attached to the horseshoe "crab" was undoubtedly even greater because many of them were knocked off or otherwise lost as the "crabs" were caught in the dredge and brought to the deck of the boat.

The bottom where the "crabs" were caught is muddy and harbors an extremely dense population of the duck clam, *Mulinia lateralis*. Probably the horseshoe "crabs," while feeding on the duck clams, scarcely had to move to find enough food, thus enabling the oyster drills to attach to their bodies. Perhaps these gastropods were attracted by juices exuding from the duck clams being crushed and eaten by the "crabs" or, in randomly moving about, they merely attached to the "crab" since it offered a hard surface in an area of soft mud.

Shuster (*4, 5*) and Baptist, Smith, and Ropes (*6*) reported that adult horseshoe "crabs" migrate each year in the early summer from deeper water to the intertidal zone to spawn. They also found that adults travel for many miles along the shore (*4, 6*). For example, Shuster (*4*), in Cape Cod Bay, Massachusetts, reported one "crab" 21 miles from the point of release. Considering the migratory habits of these animals, our observation in New Haven Harbor indicates that horseshoe "crabs" are an important distributor of oyster drills throughout the waters of Long Island Sound and, perhaps, beyond.

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A SEROLOGICAL COMPARISON OF FIVE SPECIES OF ATLANTIC CLUPEOID FISHES

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3. Erythrocyte agglutination

Three rabbits were immunized with pooled washed cells of each species tested. Six or nine .5-ml. doses were injected subcutaneously on alternate days. Trial bleedings were made 10 days after the last injection and if the antiserum titer was adequate, food was withheld and the animals bled terminally on the following day. Antisera were frozen in 3-ml. aliquots at −20° C. until absorptions and cell agglutination tests were carried out.

Cells of each clupeoid species used for antiserum absorptions were washed three times in 1.5% saline, and approximately equal amounts of erythrocytes from all individuals in the sample were pooled. Antiserum was diluted 1:4 and added to pooled cells in proportions of four parts antiserum to one part cells. After 10 minutes of absorption the cell-antiserum suspension was centrifuged and the absorbed antiserum tested against a previously removed aliquot of cells used for absorption. Absorptions of antisera to all five species with each of the five erythrocyte pools were done simultaneously, and one absorption was usually sufficient to remove all antibodies reactive with the absorbing cells. Agglutination tests were then carried out, using all possible combinations of absorbed antisera and cells from each of the five species. Each agglutination test used .2 ml. absorbed antiserum and .05 ml. of 4% cell suspension. Readings were taken after 15 minutes of incubation at room temperature and 30 seconds' centrifugation.

4. Electrophoresis

Paper electrophoresis was carried out with a Spinco Model R system for six hours at 15 milliamperes, using a veronal buffer of pH 8.6 and ionic strength of 0.05. With each run, a sample of human serum was used as a control. Each sample consisted of .01 ml. of serum. Representative curves were obtained by use of a photoelectric densitometer.

Results

1. Photronreflectometer

The results of serological comparisons of five species of clupeoids, using the photronreflectometer with one series of highly specific antisera, are summarized in Figure 1. Comparative values for reactions of each antiserum are in vertical columns beside each curve. Heterologous antigen reactions are presented in per cent of the homologous reaction. Reciprocal relationships show good agreement in most cases, especially in view of the fact that each antiserum must be considered as a separate entity as far as its specificity (discriminating capacity) is concerned.

The serological relationships of the five species presented in Figure 1 are obviously not linear, but may be expressed satisfactorily in a three-dimensional graph (Fig. 2) based on "serological distances" calculated by subtracting the per cent heterologous reaction from 100 (Boyden, 1926). This converts the relative correspondence of that particular antigen to a "relative distance" value. With this method antigens closely related to the homologous antigen will be relatively close to it, while those antigens of increasing dissimilarity will be increasingly far from the homologous. For example, in Figure 1 the serum proteins of the alewife gave a reaction that was 90% of the homologous reaction between blueback serum and

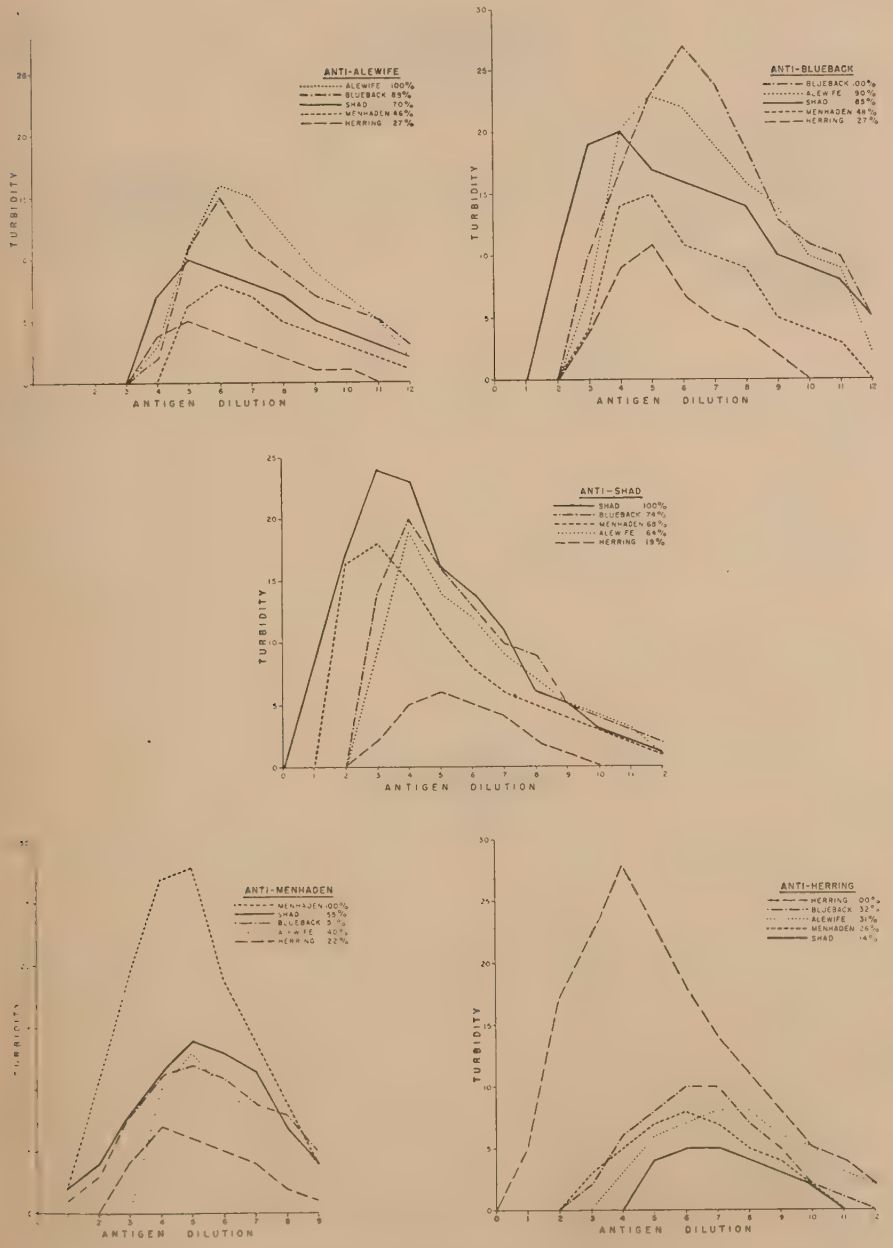

FIGURE 1. Precipitin curves derived from reactions of serum antigens of five clupeoid species with antisera prepared to each species.

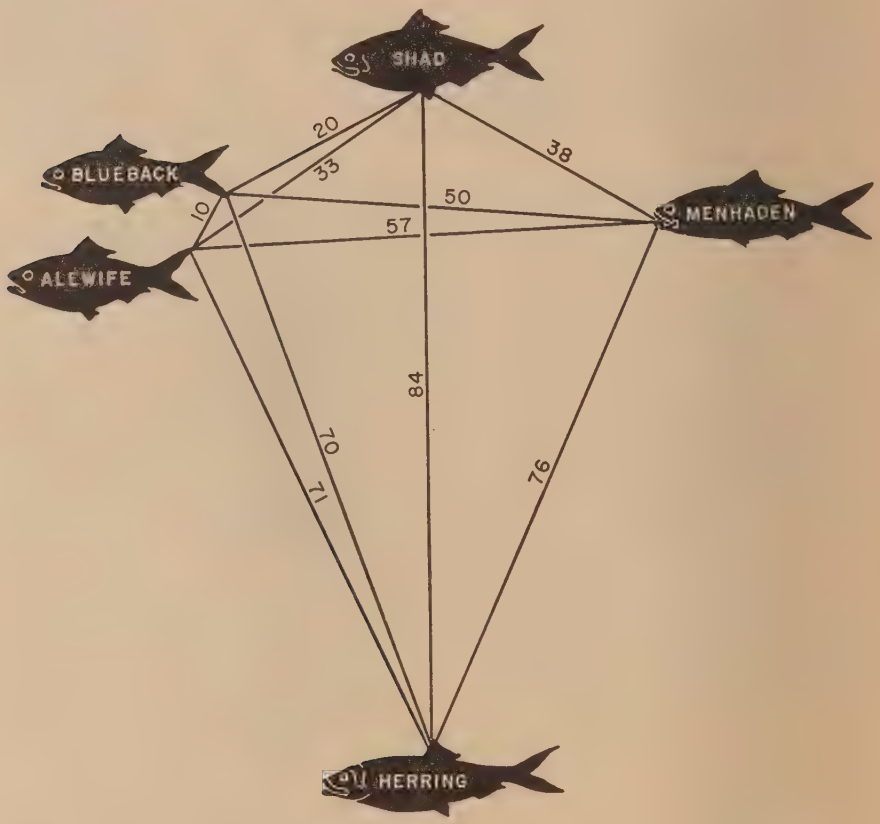

FIGURE 2. Three-dimensional representation of the present relationships of five clupeoid species, as determined from precipitin tests read with the photronreflectometer.

anti-blueback serum. The relative serological distance between blueback and alewife with this antiserum is thus 10. However, the reaction of herring serum proteins with the anti-blueback serum was only 27% of the homologous, so the relative serological distance between blueback and herring with this antiserum is 73. All relative distance values between any two species were averaged in preparation of Figure 2, and each species locus was determined by average distance values from each of the other species.

The data indicate that blueback and alewife have a high degree of serological correspondence; that shad are closer to the blueback-alewife complex than to either menhaden or herring; and that menhaden and herring are remote from all others, with herring consistently at the greatest serological distance from the other four species.

The numerical relationship values obtained are not fixed, but reflect results obtained with the particular antisera used. The relative positions of species with re-

spect to one another should, however, remain relatively constant. Boyden, DeFalco and Gemeroy (1951) and Boyden (1953) have demonstrated that despite variations in specificity and systematic range of several antisera of the same kind, a consistent placement series will emerge for the species tested. This was demonstrated in the present work by a second series of antisera with lower specificity obtained by deliberately prolonged injections extending over a one-month period. Such antisera were in most instances less specific, but no variations in relative placement of the five species occurred. Serological distances separating heterologous and homologous species were reduced in most cases, but relative positions and placements were similar.

2. Agar diffusion

Clear patterns of precipitate were obtained with each of the antisera used. Although minor differences were noticed in the discriminating capacity of different rabbits immunized against the same species, the reproducibility was high with respect to number and position of precipitate bands in the gel. Diagrammatic sketches of typical patterns appear in Figure 3.

Since results of agar plate tests are very difficult to quantitate, they are not as useful for the determination of exact serological distances between species as the photronreflectometer. However, since closely related species display similar reactions and share some precipitate bands in reactions of identity, it is possible to get a good general idea of the relationships involved.

Alewife and blueback sera showed very similar reciprocal reactions. Shad serum reacted strongly to antisera prepared against alewives and bluebacks and shared some precipitate bands with these species, but the reciprocal reactions were somewhat weaker; thus, in the overall picture shad must be placed slightly farther from alewives and bluebacks than these two species are from one another. Menhaden and herring appear to stand somewhat apart from the alewife-blueback-shad complex, but the reactions of menhaden showed a closer relationship to that group than did those of herring. Apparently, menhaden and herring have very little taxonomic affinity, for antisera prepared against either of these species evoked only the faintest traces of precipitate from sera of the other, and these trace reactions were always of the type representing complete non-identity of antigens.

The results of the agar diffusion tests substantiate the more precise picture of relationships shown by the photronreflectometer. The positions of the species are in the same orientation as those deduced from the turbidimetric measurements.

3. Erythrocyte agglutinations

Tests were made with reagents obtained by absorbing each antiserum with cells of each of the five species. The reactions (Table I) represent composites of three separate tests, each using different samples of fish blood and a different antiserum. Results are recorded conventionally in descending order from (++++), representing complete agglutination, to (−) representing no agglutination.

The reduction in strength of agglutinations after absorptions indicates that all antisera contained substantial amounts of cross-reactive antibodies. Alewife and blueback cells shared many antigens, so that absorptions with either gave very similar but not identical reactions. Shad and menhaden shared some antigens, so

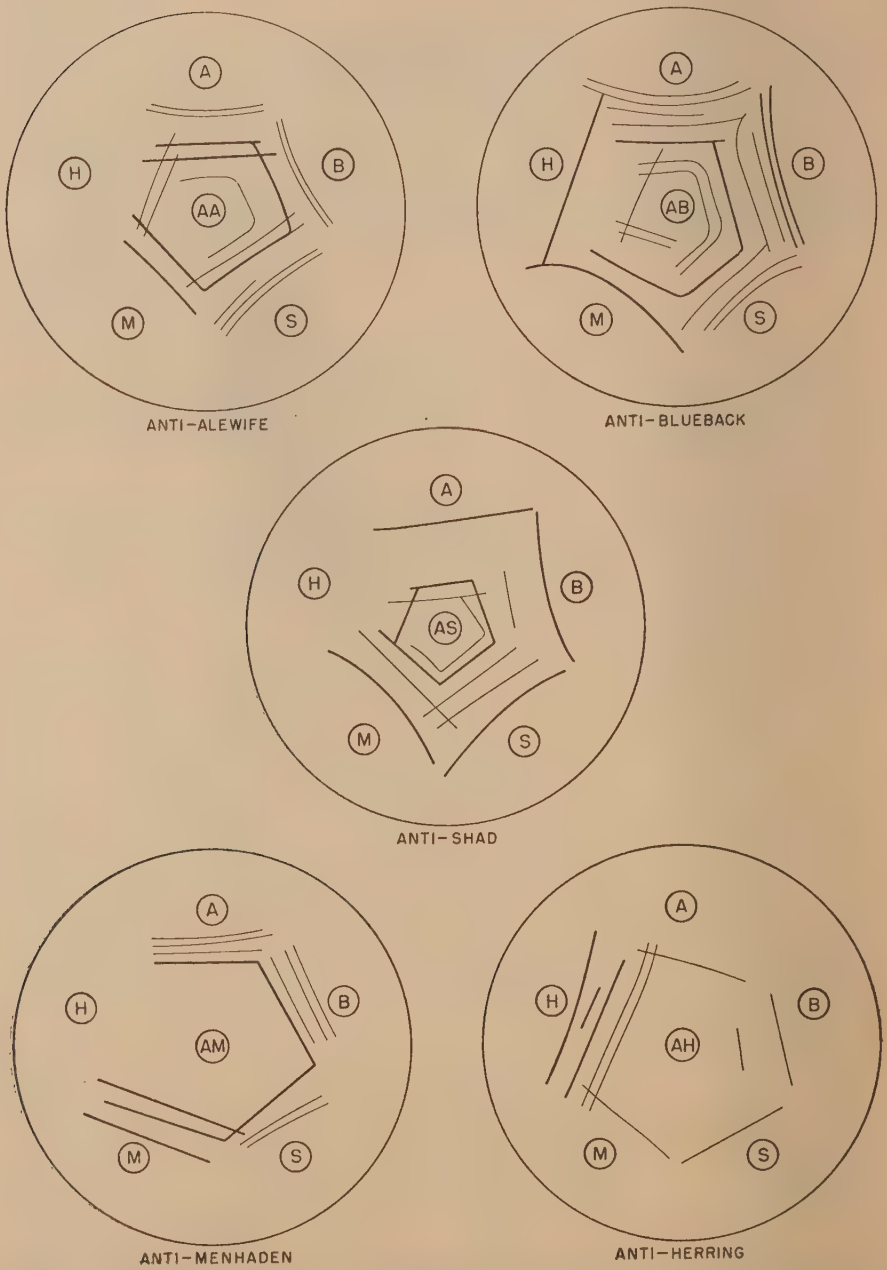

FIGURE 3. Diagrams of reactions in representative agar diffusion plates for each of the five clupeoid species. A = alewife, B = blueback, H = herring, M = menhaden, S = shad.

TABLE I

Reactions of erythrocytes of five clupeoid species with absorbed antisera

Antiserum	Cells used in absorptions	Agglutination reactions				
		Alewife	Blueback	Herring	Menhaden	Shad
Alewife	Alewife	−	−	−	−	−
	Blueback	+	−	+	−	−
	Herring	+++	++	−	−	+
	Menhaden	+++	++	++	−	−
	Shad	++	+	++	−	−
	Unabsorbed	+++	++	+++	+	++
Blueback	Alewife	−	−	+	−	−
	Blueback	−	−	−	−	−
	Herring	++	+	−	−	−
	Menhaden	++	+	+++	−	−
	Shad	++	+	++	−	−
	Unabsorbed	++++	+++	++++	+	++
Herring	Alewife	−	−	+	−	−
	Blueback	+	−	++	−	−
	Herring	−	−	−	−	−
	Menhaden	+	+	+++	−	−
	Shad	−	−	++	−	−
	Unabsorbed	++++	++	+++	+	++
Menhaden	Alewife	−	−	++	+	+
	Blueback	+	−	++	+	+
	Herring	+	+	−	+	+
	Menhaden	−	−	−	−	−
	Shad	+	+	++	+	−
	Unabsorbed	+++	++	+++	++	++
Shad	Alewife	−	−	+++	+	++
	Blueback	+	−	+++	++	++
	Herring	+	−	−	++	++
	Menhaden	+++	++	+++	−	+
	Shad	−	−	−	−	−
	Unabsorbed	+++	++	+++	+++	+++

that absorptions gave a somewhat similar pattern of reactions, although the relationship was by no means as close as that of alewife and blueback.

4. Electrophoresis

Electrophoretic analyses were made with both pooled and individual sera. Individual sera appeared in all cases to give better definition of components, although they conformed to the general pattern of the pools. Considerable intraspecific variation in patterns was evident, but a generalization of each species pattern was possible. The curves derived from these generalized patterns are depicted in Figure 4, as determined by densitometer readings; they are, however, not intended to illustrate absolute species specificity. The numbers designating each peak are

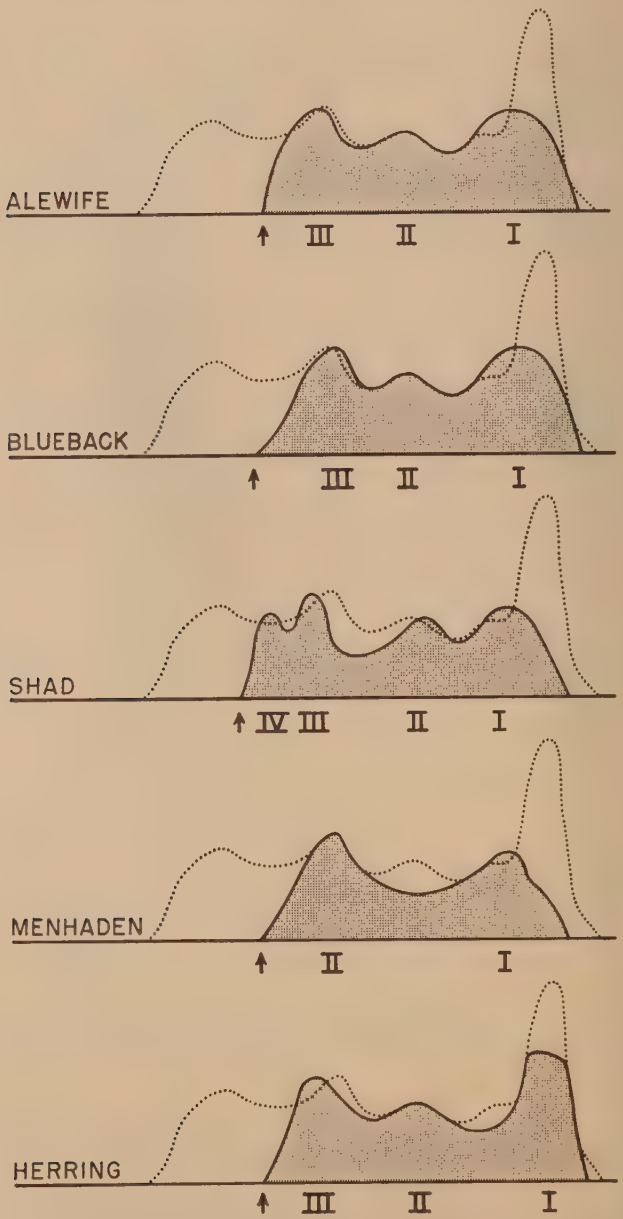

FIGURE 4. Representative paper electrophoresis diagrams for five clupeoid species as determined by densitometer readings. Dotted line represents human serum used as control.

used for ease in description and do not denote identity of components between species.

The alewife and blueback sera displayed very similar electrophoretic patterns, each with three major fractions. The main difference between the two species was found in the least mobile fraction; in alewives this fraction was less mobile than human beta globulin, whereas in bluebacks it migrated further than human beta globulin. Both species had a weak fraction of the same mobility as human alpha-2 globulin, and a fraction of slightly less mobility than human albumin. In some specimens of alewife, a weak fourth fraction appeared, intermediate in mobility between the human alpha-2 and beta globulin fractions.

The shad samples tested displayed a pattern of four fractions. The least mobile of these did not migrate as far from the point of application as human beta globulin. A strong fraction with slightly more mobility was present in all specimens, as were moderate fractions with slightly more mobility, respectively, than human alpha-2 and alpha-1 globulins.

The pattern shown by the menhaden sampled had two fairly strong fractions. One of these was identical in mobility to human beta globulin, and one was intermediate between human alpha-1 globulin and albumin.

Three moderately strong fractions were obvious in the patterns of the sea herring tested. The least mobile migrated a shorter distance than human beta globulin, while the others travelled the same distances, respectively, as human alpha-2 globulin and albumin. In some fish of this species a fourth fraction appeared which was intermediate between human alpha-1 globulin and albumin.

Discussion

1. Photronreflectometer

The clear differentiation of five clupeoid species with this precipitin technique read photoelectrically offers tempting possibilities for future studies. It would be interesting, with the background of the present data, to compare other morphologically similar but geographically isolated clupeoid species. Suspected hybrids, such as those between *Alosa pseudoharengus* and *A. aestivalis* might also be examined serologically. Comparison of populations or "races" of cosmopolitan species, such as *Clupea harengus,* with serum techniques might also prove instructive.

The limitations of such studies must be kept in mind. Results of serological examinations would not be considered as the sole criterion for taxonomic conclusions, but should be evaluated together with morphological and other data to provide as broad a base as possible for such conclusions. Information about the possible influences of environmental and physiological changes on serological reactions should be obtained. It should also be emphasized that results will indicate present serological relationships, but will give only indirect information about the evolutionary history of the species concerned. Despite such limitations, serum techniques offer possibilities in fisheries research that should be explored as vigorously as other techniques for the understanding of natural relationships.

2. Agar diffusion

Further experimentation should be conducted with agar diffusion to determine its usefulness in studies on fish populations. Absorption of antisera to remove spe-

cies antibodies would probably be a virtual necessity for work at the intraspecific level.

The advantage of this type of test obviously lies in the fact that the total precipitate is resolved into its component antigen-antibody reactions, which are subject to direct visual observation. While this permits a high degree of qualitative differentiation and gives a good idea of general species relationship, it is very difficult to measure exactly the total amount of precipitate formed. For this reason, it is best to leave the final calculation of relative serological distances between species to turbidimetric methods, keeping in mind the fact that rabbits or other experimental animals are not the exclusive and final arbiters of natural relationships.

3. Erythrocyte agglutination

The use of pooled cells to absorb antisera to all five clupeoids, and the subsequent testing of such pools with reagents obtained by absorptions, have provided a criterion for determining the relationships of five clupeoid species. It would be instructive to apply this test to additional clupeoid species in other regions.

Another logical extension of this work would be determination of the distribution of similar or identical antigens in individual blood samples of the five species. Individual differences have been noted in the present work for all five species, but, except for herring, blood group systems have not been proposed. The use of pooled cells masks individual differences, and it is obviously less precise than a study of discrete antigens with specific reagents. To test the utility of the single antigen approach, individual samples of all species were tested with the reagents used in routine examination for the C blood group antigen of herring (Sindermann and Mairs, 1959). Positive reactions were obtained with most alewives, half of the bluebacks, a few shad, and no menhaden, indicating the existence of the same or at least a closely related antigen in species other than herring. Similar tests with other specific reagents could create a mosaic of reactions that would provide a clearer picture of the affinities disclosed by the present study. The utility of such an approach has already been demonstrated with certain mammalian species by Stormont and Suzuki (1958).

4. Electrophoresis

Although it was possible to construct electrophoretic patterns characteristic of the five species of clupeoids, the intraspecific variations encountered in this study and in an electrophoretic examination of herring populations (Mairs and Sindermann, 1960) indicate that great caution should be employed in the establishment of specific patterns for teleostean species. It has been shown that the component fractions of serum display variability in both quantity and electrophoretic mobility depending on such factors as disease, age, sex and starvation (Moore, 1945; Dessauer and Fox, 1956; Drilhon *et al.*, 1956; Sindermann and Mairs, 1958). This variability could lead to significant overlap and confusion of patterns, especially among closely related species. In many cases, it is doubtless possible to characterize a high proportion of the electrophoretic patterns in a sample, but proposal of a species-specific pattern would have to follow testing of a large number of individuals, with close reference to maturity, disease, and any other physiological or environmental factor known or likely to affect electrophoretic characteristics. Only in

this way could a species "norm," if such exists, be properly defined and an insight gained on the true significance of the variations encountered.

The present study indicates that, while paper electrophoresis may have some general usefulness in fish taxonomy, immunological techniques are preferable for precise differentiation and attempts at determining natural relationships.

Summary and Conclusions

1. An investigation of the serological relationships of five species of clupeoid fishes was made by four methods: (a) photronreflectometer, (b) agar diffusion, (c) erythrocyte agglutination with absorbed antisera, and (d) paper electrophoresis.

2. Agar diffusion enabled qualitative differentiation of the species tested, while the photronreflectometer provided a quantitative measure of relative serological distances between species; results from the two methods were in good agreement.

3. On the basis of results obtained by the photronreflectometer and agar diffusion methods, the following species relationships are indicated: alewives and bluebacks are very closely related; shad lie quite close to alewives and bluebacks, but farther from them than alewives and bluebacks are from one another; menhaden and herring are further removed from the alewife-blueback-shad complex, with menhaden closer to it than herring; herring are comparatively remote from the other four species.

4. Generalized electrophoretic patterns were found for each clupeoid species. However, because of intraspecies variability, paper electrophoresis does not seem to be as useful a procedure for determining relationships of fishes as immunological methods. Species-specific patterns should be proposed only after large numbers of individuals representing both sexes have been sampled under different physiological conditions.

5. Absorptions of rabbit antisera with pooled erythrocytes of each of the five clupeoid species indicated that alewife and blueback were antigenically very similar; menhaden and shad were antigenically somewhat similar, although not as close as alewife and blueback.

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THE CAUSES OF MAJOR VARIATIONS IN THE CATCH OF THE PACIFIC SARDINE, *Sardinops caerulea* (Girard)

by

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Abstract

Reviews the historical record of the Pacific sardine fishery and the biology of the species, and develops a model which offers an explanation of the decline of the fishery : Sardines which support the United States and Canadian catch are produced off southern California and central Baja California. Those produced off southern California migrate as far north as British Columbia, support the fishery there and contribute to the fisheries at San Francisco, Monterey and San Pedro. Those produced off central Baja California migrate as far north as central California and contribute to the California fisheries, especially at San Pedro. Lack of spawning success on the southern California spawning grounds since about 1943 could account for the observed changes in the fishery.

Lack of spawning success off southern California is attributed to environmental conditions.

Several aspects of age and length data are considered, and the question of availability and the general effect of a fishery upon a population are briefly reviewed.

Models previously developed are discussed, and related to the model presented here.

LES CAUSES DES VARIATIONS LES PLUS IMPORTANTES DANS LA PECHE DE LA SARDINE DU PACIFIQUE (Sardinops caerulea, Girard)

Résumé

L'auteur fait l'historique de la pêche à la sardine et des connaissances relatives à la biologie de cette espèce. Sur la base de ces données, il établit le schéma suivant qui permet d'expliquer le déclin de la pêche : les sardines qui alimentent la pêche du Canada et des Etats-Unis proviennent des zones situées au large de la Californie méridionale et du milieu de la Basse Californie. Celles qui proviennent des zones situées au large de la Californie méridionale émigrent vers le nord jusqu'en Colombie britannique, dont elles alimentent la pêche ainsi qu'une partie de celle de San Francisco, de Monterey et de San Pedro. Celles qui proviennent de la zone située au large du milieu de la Basse Californie émigrent vers le nord jusqu'au littoral de la Californie centrale où elles alimentent une partie des pêches californiennes, principalement de San Pedro. La baisse de production des lieux de frai de la Californie méridionale enregistrée depuis 1943, pourrait expliquer le recul de la pêche; elle est attribuée au changement des conditions du milieu.

L'auteur examine les questions relatives aux catégories d'âges et de longueurs et fait un bref exposé sur la disponibilité, et l'effet général d'une pêche sur la population.

Il étudie enfin les schémas établis précédemment, et les relie au présent schéma.

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LAS CAUSAS DE LAS VARIACIONES MAS IMPORTANTES EN LAS CAPTURAS DE LA SARDINA DEL PACIFICO (Sardinops caerulea, Girard)

Extracto

Se analiza aquí el historial de la pesca y la biología de la sardina, a la luz del cual se da una explicación al descenso experimentado en la pesquería, a saber : las sardinas de que se sostienen las capturas de los Estados Unidos y las del Canadá se reproducen en aguas al sur de la Alta California y en la Baja California central. Las del sur de la Alta California emigran al Norte, llegando hasta la Columbia Británica, cuya pesca alimentan, contribuyendo también a las pesquerías de San Francisco, Monterey y San Pedro. Las de la Baja California central alcanzan en sus migraciones hacia el Norte la Alta California central y contribuyen a las pesquerías californianas, y especialmente a la de San Pedro. Los cambios observados en la pesquería podrían obedecer a las fallas del desove que se vienen registrando en los lugares de puesta aproximadamente desde 1943.

Las fallas del desove en las aguas al sur de la Alta California se atribuyen a las condiciones ambientales.

Se estudian varios aspectos de los datos relativos a la edad y la talla, analizandose tambien brevemente la cuestión de la disponibilidad de extracción y el efecto general de una pesquería sobre una población.

Se exponen, asimismo, explicaciones o teorías desarrolladas con anterioridad y se relacionan a las aquí expuestas.

1 INTRODUCTION

The decline in the catch of the Pacific sardine, Sardinops caerulea (Girard), in the mid-1940's is a well known fact. Because of the spectacular nature of the decline, because of the great economic hardship it engendered, and because of the considerable resources expended on investigating this problem[2/] the question "What happened to the sardine?" has frequently and justifiably been asked. The problems encountered in attempting to answer this question are varied and complex. The answer is not simple and, indeed, may lack the definitiveness for which many would hope. In this attempt to achieve an answer, events not only prior to and during the decline, but also during the subsequent decade, as well as possible future trends, are considered.

The findings presented here are a contribution from the California Cooperative Oceanic Fisheries Investigations. CCOFI objectives have been stated (California Marine Research Committee, 1958:8) as "To determine what controls variations in population size and availability in oceanic fishes off the west coast of North America", with particular emphasis on the Pacific sardine and ecologically and economically associated species. CCOFI studies are sponsored by the California Marine Research Committee and are carried out by the California Academy of Sciences, California Department of Fish and Game, Hopkins Marine Station of Stanford University, Scripps Institution of Oceanography of the University of California, and the Biological Laboratory at La Jolla (formerly the South Pacific Fishery Investigations) of the U.S. Bureau of Commercial Fisheries.

In examining this broad problem, I have attempted to draw upon all available data and lines of evidence. Attention has been concentrated on information available from previously unanalyzed data, and to extracting additional information from data previously used in attacking specific and often quite different problems. Subjects considered in detail elsewhere are not so dealt with here, as will be apparent from the references throughout the text. Therefore, the reader may wish to refer to Schaefer, Sette and Marr (1951) for a description of the growth of the fishery, Clark (1952) for a review of the California fishery, Clark and Marr (1955) for a summary of sardine biology and population dynamics, and Ahlstrom (1954a, 1959) for information on the distribution and abundance of eggs and larvae.

2/ These investigations have often been referred to as the largest fishery investigations in terms of financial support. It is pointed out that at least four other investigations of equal or greater importance from that standpoint are those of: (1) the International Commission for the Northwest Atlantic Fisheries, (2) the Great Lakes Fishery Commission, (3) the International North Pacific Fisheries Commission, and (4) those on the tunas of the central and eastern Pacific.

2 HISTORICAL RECORD - CATCH DATA

2.1 Total landings

Table I gives data on sardine landings from the 1916-17 through 1958-59 seasons for the four fishing areas. Total landings on the Pacific coast of North America, as well as landings in British Columbia and San Francisco, Monterey, and San Pedro, are illustrated in Fig. 1. The British Columbia fishery was carried out in the summer months; the California fishery in the fall and winter months. The season at San Francisco and Monterey began and ended earlier than at San Pedro. The British Columbia season was not fixed by law, but was determined by the presence of fish. The California seasons were fixed by law, primarily as the result of the presence of fish and certain economic conditions (Schaefer et al., 1951). In combining catch statistics, the summer fishery in British Columbia has been included with the following fall and winter fishery in California. Thus, for example, the 1941 summer catch in British Columbia and the 1941-42 fall and winter catch in California are all considered to be the catch in the 1941-42 season.

Catch records have been reviewed by many individuals, perhaps most recently and comprehensively by Clark and Marr (1955) and by Schaefer et al. (1951). The latter work is particularly pertinent to Fig. 1. The authors showed that the growth of the sardine industry, as revealed by total landings from the 1916-17 through 1941-42 seasons, could be described by a logistic curve, with an asymptote of about 600,000 tons. The wide variations about the fitted curve were shown to be related in large degree to economic conditions. There were smaller residual deviations for which no firm explanation could be offered.

The total sardine landings continued to fluctuate around 600,000 tons through the 1944-45 season (Fig. 1). Following this season, the logistic fit no longer obtains and the catch declined through the 1947-48 season, recovered to slightly more than half the former magnitude in the 1949-50 and 1950-51 seasons, declined again to all-time (post 1916-17) lows in the 1952-53 and 1953-54 seasons, and has since varied below 100,000 tons. The catch of the 1958-59 season slightly exceeded 100,000 tons and would have been even greater had it not been for economic limitations 3/ Even so, the 1958-59 catch exceeded those of the preceding six seasons.

3/ Diverse factors have contributed to the present unfavourable economic position of the sardine industry. Raw material and operating costs have gone up. Meal and/or oil markets have been lost to vegetable competitive items and to other U.S. and foreign (especially South American and South African) fishery competitive items, or because of the development of new products. Overseas canned goods markets have been taken over by foreign (especially Japanese and South African) canned goods. Domestic canned goods markets have been lost because of the rise in the standard of living of former consumers, and their subsequent utilization of other and more expensive protein sources.

Table I

SARDINE LANDINGS ALONG THE PACIFIC COAST OF NORTH AMERICA
(EXCLUDING MINOR AMOUNTS LANDED IN MEXICO)[4/]
(In 1,000s of tons)

Season	United States										British Columbia	Total all ports
	California							Oregon	Wash-ington	Total		
	Shore plants					High seas plants	Total					
	San Diego	San Pedro	Monterey	San Francisco	Total							
1916-17	5	18	9	-	32	-	32	-	-	32	-	32
1917-18	8	43	24	-	75	-	75	-	-	75	-	75
1918-19	6	30	35	-	72	-	72	-	-	72	4	76
1919-20	7	16	46	1	70	-	70	-	-	70	3	73
1920-21	1	12	28	-	41	-	41	-	-	41	4	45
1921-22	1	19	18	-	38	-	38	-	-	38	1	39
1922-23	3	33	30	-	66	-	66	-	-	66	1	67
1923-24	3	35	46	-	84	-	84	-	-	84	1	85
1924-25	9	96	68	1	174	-	174	-	-	174	1	175
1925-26	5	62	69	-	136	-	136	-	-	136	16	152
1926-27	-	64	77	3	144	-	144	-	-	144	48	192
1927-28	4	68	99	11	182	-	182	-	-	182	68	250
1928-29	1	119	119	13	252	-	252	-	-	252	81	333
1929-30	2	140	159	21	322	-	322	-	-	322	86	408
1930-31	-	39	109	24	172	11	183	-	-	183	75	258
1931-32	-	43	69	20	132	31	163	-	-	163	74	237
1932-33	-	83	89	17	189	59	248	-	-	248	44	292
1933-34	1	125	152	36	314	68	382	-	-	382	3	385
1934-35	5	179	230	67	481	116	597	-	-	597	43	640
1935-36	10	138	184	74	406	151	557	26	-	583	46	629
1936-37	5	138	206	139	488	236	724	14	7	745	44	789
1937-38	-	109	104	132	345	68	413	17	17	447	48	495
1938-39	3	145	180	200	528	44	572	17	26	615	52	667
1939-40	-	93	227	211	531	-	531	22	18	571	6	577
1940-41	1	171	165	118	455	-	455	3	1	459	29	488
1941-42	2	146	250	186	584	-	584	16	17	617	60	677
1942-43	3	202	184	116	505	-	505	2	1	508	66	574
1943-44	3	135	214	127	479	-	479	2	10	491	89	580
1944-45	3	178	237	137	555	-	555	-	-	555	59	614
1945-46	1	173	146	84	404	-	404	-	2	406	34	440
1946-47	5	195	31	3	234	-	234	4	6	244	4	248
1947-48	2	101	18	+	121	-	121	7	1	129	-	129
1948-49	4	132	48	+	184	-	184	5	-	189	-	189
1949-50	3	185	128	18	334	-	334	-	-	334	-	334
1950-51	3	303	32	13	351	-	351	-	-	351	-	351
1951-52	1	110	16	-	127	-	127	-	-	127	-	127
1952-53	-	4	-	-	4	-	4	-	-	4	-	4
1953-54	-	3	-	-	3	-	3	-	-	3	-	3
1954-55	-	66	-	-	66	-	66	-	-	66	-	66
1955-56	-	73	-	-	73	-	73	-	-	73	-	73
1956-57	-	33	-	-	33	-	33	-	-	33	-	33
1957-58	-	21	-	-	21	-	21	-	-	21	-	21
1958-59	-	78	24	-	102	-	102	-	-	102	-	102

4/ Data through 1941-42 from Table 2, Schaefer et al., (1951); data for 1942-43 through 1956-57 from Felin et al. (1948, 1949, 1950, 1951, 1952, 1953, 1954, 1955 and 1958), from Mosher et al. (1949), from Wolf et al. (1958); and from Clark (1952); data for 1957-58 from Daugherty and Wolf (1960); data for 1958-59 through the courtesy of the California Department of Fish and Game. In reporting landings in 1,000's of tons, minor landings will obviously be omitted; for example, at San Francisco there were landings of 82 tons in 1947-48 and 499 tons in 1948-49; such landings have been indicated by a "+" in the table (while "-" indicates zero landings). Other data (age composition for example) may be used for "+" seasons in subsequent sections of the paper.

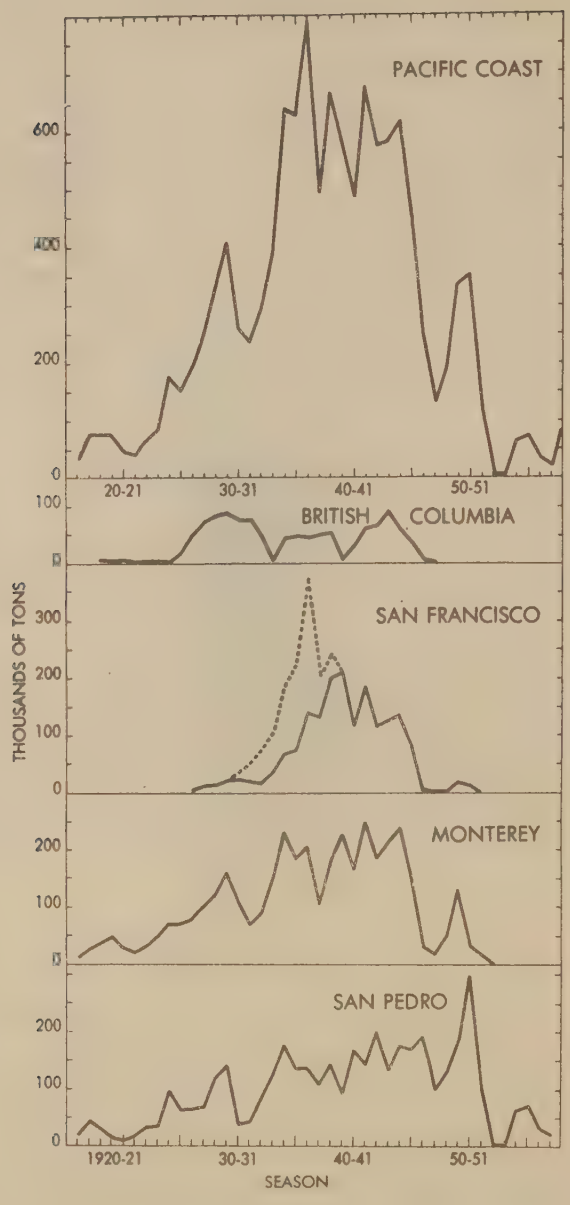

Fig. 1 Sardine landings along the Pacific coast of North America (excluding minor amounts landed in Mexico). Data are from Table I.

2.2 Landings by ports

While the curve of total landings reveals, in general, the history of the fishery, curves of landings by ports are more instructive. They reveal both continuities and discontinuities in space and time.

Although small landings are recorded commencing with the 1918-19 season, the British Columbia fishery started its major growth in the 1925-26 season, following which the catch fluctuated around 50,000 tons per year. The curve of British Columbia landings shows little or no effect of the economic depression of the early 1930's. In fact, the two seasons of greatly reduced catches, 1933-34 and 1939-40, were caused by neither economic conditions nor reduced total abundance of the sardine. Rather, they were caused by greatly reduced availability of the sardine which in those seasons did not migrate as far north as usual to the British Columbia fishing grounds (Clark and Marr, 1955: 33). The final decline of this fishery followed the 1943-44 season, and since the 1946-47 season the species has apparently not appeared in commercial quantities in British Columbia waters, although occasional specimens are taken incidentally in other fisheries (Reid, 1960).

The San Francisco sardine fishery started in the 1926-27 season, a decade later than the fisheries at Monterey and San Pedro. The total catch curve (for shore plants) shows little effect of the depression. Following the 1936-37 season, landings fluctuated around 150,000 tons per year. Landings were, however, also made at high seas plants in the offing of San Francisco from the 1930-31 through 1938-39 seasons, and are indicated by the dashed line in Fig. 1. Although substantial deliveries were made to these plants in several seasons, they did not continue operations owing to a complex of economic and legal difficulties. The decline in landings at San Francisco followed the 1944-45 season. However, if the landings at high seas plants are included, the total landings declined more or less continuously from the 1936-37 season. There were no landings in the 1947-48 and 1948-49 seasons. Minor landings of under 20,000 tons were made in the 1949-50 and 1950-51 seasons, and then they ceased altogether.

The Monterey fishery started its growth at the time of World War I. The curve of total landings reflects the economic recessions of the early 1920's and, especially, of the early 1930's. Following the 1933-34 season, the annual catch fluctuated around a level of about 190,000 tons. The decline in catch followed the 1944-45 season, and fell to slightly less than 20,000 tons in the 1947-48 season. The landings recovered to about 130,000 tons in the 1949-50 season, and then fell sharply. There was no fishery following the 1951-52 season until the 1958-59 season, when about 24,000 tons were landed.

The San Pedro fishery, like the Monterey fishery, also developed about the time of World War I and showed the effects of the economic recessions, although somewhat in advance of the Monterey fishery. Following the 1932-33 season, the total catch was about 150,000 tons. The catch did decline following the 1946-47 season, but not below the range of experience of the previous 15 seasons. In the 1950-51 season, the catch "recovered" to slightly over 300,000 tons. A catch of this magnitude had never before been experienced at San Pedro, nor indeed at any

other port, save San Francisco in the 1936-37 season, when the combined high seas plant and shore plant landings exceeded 370,000 tons. Following the 1950-51 season, the catch declined to all-time lows in the 1952-53 and 1953-54 seasons. A partial recovery to about 70,000 tons was made in the 1954-55 and 1955-56 seasons, followed by another decline in the next two seasons. Another partial recovery was made to about 78,000 tons in 1958-59, and the catch would have been even greater had it not been for unfavorable market conditions. Even so, the 1958-59 landings were comparable to those experienced at San Pedro in the 1932-33, 1937-38, 1939-40, 1947-48, and 1951-52 seasons.

The features of the initial decline in landings and the subsequent history of the fisheries in these four areas may be summarized as follows :

(a) the initial decline was not simultaneous; it followed the 1943-44 season in British Columbia, the 1944-45 season in San Francisco and Monterey, and the 1946-47 season in San Pedro;

(b) the initial decline was not equally severe in all areas; the catch in British Columbia and San Francisco fell to zero, was greatly reduced at Monterey, while at San Pedro it was not outside what might be considered the normal variation of the previous 15 seasons;

(c) the first recovery did not occur simultaneously in all areas; it did not occur at all in British Columbia, it occurred in the 1949-50 season at San Francisco and Monterey, and in the 1950-51 season at San Pedro;

(d) the first recovery was not of the same magnitude in all areas; non-existent in British Columbia, it was quite small at San Francisco, not quite 70 per cent of the previous level at Monterey, and 200 per cent of the previous level at San Pedro;

(e) the second recovery occurred only at San Pedro in the 1954-55 and 1955-56 seasons, and was not quite 50 per cent of the pre-decline level;

(f) the third recovery occurred in the 1958-59 season, and only at Monterey and San Pedro. It was slight at Monterey, but approached the pre-decline level at San Pedro. At both ports the landings were limited by economic conditions.

2.3 Catch per unit-of-effort

Catch per unit-of-effort data have been given for the British Columbia fishery for the 1925-26 through 1932-33 seasons (Hart, 1933), for the Oregon-Washington fishery for the 1935-36 through 1943-44 seasons (Marr, 1950), and for the California fishery for the 1932-33 through 1954-55 seasons (Silliman and Clark, 1945; Clark and Daugherty, 1950, 1952; and Clark, 1956). These data have recently been re-examined by Clark and Marr (1955). The California data are of greatest interest, since they are available for the longest period and include the initial decline of the fishery.

In considering catch per unit-of-effort data, it is well to remember that even though such data are frequently interpreted as indicating changes in population size, this is not precisely what they measure; rather, they indicate the density of fish on the fishing grounds. Density on the fishing grounds is a function of both abundance and availability (as defined by Marr, 1951), for which the collective term "apparent abundance" has been proposed (Marr, 1950). Availability phenomena have been of importance in the sardine fishery (see 3.4). Catch per unit-of-effort data should be regarded as indices only, as they are of relative rather than absolute significance between seasons. In the specific case of the sardine data, the relative changes between seasons will be influenced by the particular base year selected. Thus, with reference to the sardine data, greatest significance should be attached to the direction of change between seasons. Less significance should be attached to the absolute magnitude of change, and little or no direct significance to the absolute values.

Data on catch per unit-of-effort and amount of effort for the 1932-33 through 1954-55 seasons for all of California and at San Francisco, Monterey and San Pedro, are given in Table II and illustrated in Fig. 2. Again, the data by ports are more instructive than the data for all California ports combined.

Catch per unit-of-effort at San Francisco (including the landings at high seas plants) increased from the 1932-33 to the 1934-35 season, when it reached an all-time high. It then declined to the 1937-38 season, at which time it was slightly less than 40 per cent of the 1934-35 value. It increased to the 1941-42 season, when it approximated the 1932-33 value. Catch per unit-of-effort remained at about this level for three seasons. Following the 1943-44 season, it declined to an all-time low of about 25 per cent of the 1934-35 season in the 1945-46 season. Catch per unit-of-effort data were not calculated for subsequent seasons owing to the complete absence or negligible size of the fishery at San Francisco.

There is little, if any, correlation between catch per unit-of-effort and total catch at San Francisco (Fig. 3). Such a relationship would not be expected unless the amount of effort tended to remain relatively constant. This condition did not obtain at San Francisco, as will be discussed later.

Catch per unit-of-effort at Monterey rose, as it did at San Francisco, from the 1932-33 season to an all-time high in the 1934-35 season. Similarly, it then declined to the 1937-38 season to not quite 35 per cent of the 1934-35 rate. Following the 1937-38 season, catch per unit-of-effort at Monterey fluctuated at about half that of the 1934-35 season until the 1944-45 season. In the following three seasons, catch per unit-of-effort declined again to about 15 per cent of the previous level. It recovered again in the 1949-50 season to about the middling level of the late 1930's and early 1940's, but declined again in the 1950-51 season to the previous low level. Catch per unit-of-effort data have not been computed for subsequent seasons, owing to the negligible size or complete absence of a fishery.

Changes in catch per unit-of-effort at Monterey closely follow changes in catch (Fig. 4). The association between direction of change is rather consistent throughout the series. The association between relative magnitude of change is consistent following the first five seasons.

Table II

CATCH PER UNIT-OF-EFFORT AND EFFORT DATA FOR THE CALIFORNIA SARDINE FISHERY (CALCULATED WITH 1941-42 AS THE BASE SEASON)

Season	San Pedro 5/		Monterey 5/		San Francisco 6/		California 5/	
	c/u tons	boat - months	c/u tons	boat - months	c/u tons	boat - months	c/u tons	boat - months
1932-33	578	144	681	131	517	147	557	447
1933-34	781	162	677	224	568	182	626	600
1934-35	838	219	1050	219	795	231	835	715
1935-36	594	251	742	241	735	306	638	874
1936-37	452	315	787	262	655	572	586	1236
1937-38	277	393	365	286	334	599	302	1368
1938-39	352	420	566	318	356	685	409	1401
1939-40	277	336	589	386	435	486	405	1312
1940-41	405	424	458	360	470	251	404	1125
1941-42	332	445	553	451	572	325	447	1306
1942-43	480	422	532	344	491	236	497	1008
1943-44	282	479	565	376	488	258	422	1123
1944-45	448	396	524	448	282	483	420	1304
1945-46	393	434	304	468	214	391	302	1313
1946-47	256	772	66	408	-	-	153	1487
1947-48	116	825	35	409	-	-	81	1356
1948-49	246	476	117	345	-	-	173	918
1949-50	416	453	440	292	-	-	352	948
1950-51	314	966	88	366	-	-	229	1531
1951-52	187	594	-	-	-	-	187	594
1952-53	10	466	-	-	-	-	10	466
1953-54	11	296	-	-	-	-	11	296
1954-55	145	458	-	-	-	-	145	458

5/ From Clark and Daugherty (1952) through 1950-51; from Clark (1956) subsequently.
6/ Derived from Clark and Daugherty (1950).

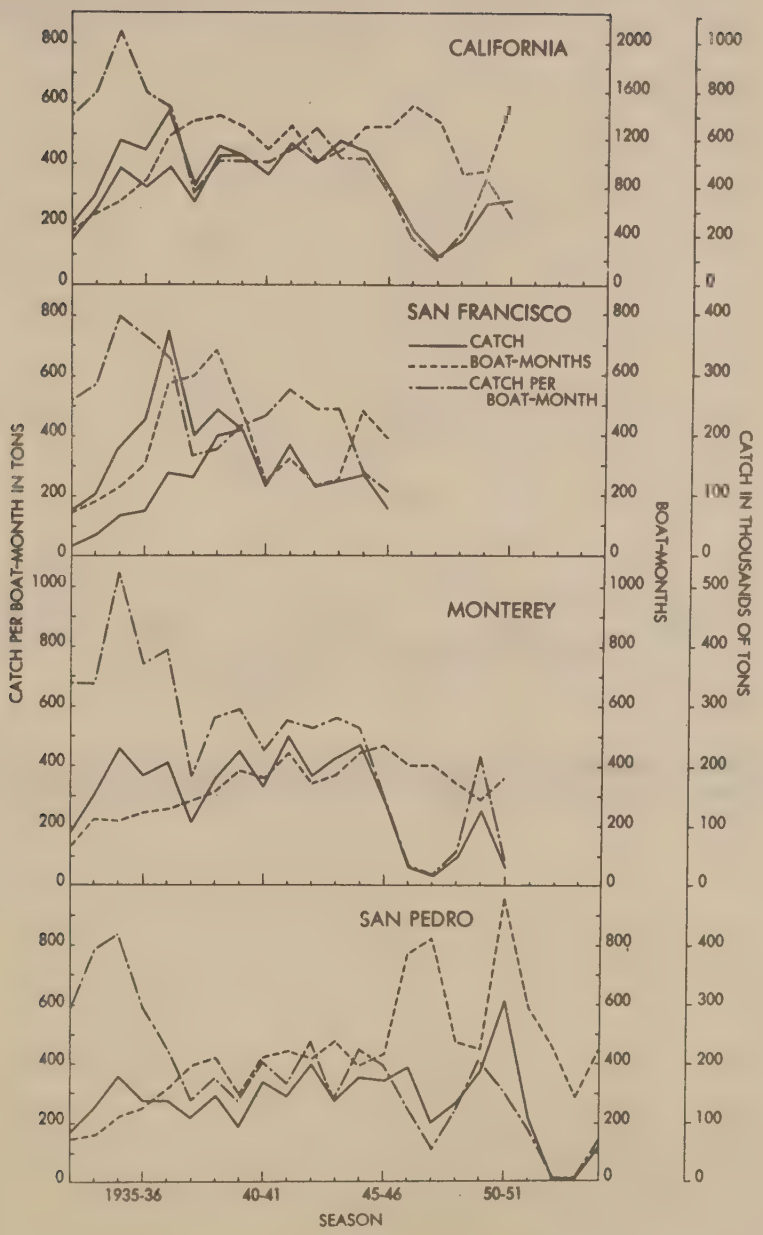

Fig. 2 Catch per unit-of-effort, effort and total catch data for California as a whole and for the ports of San Francisco, Monterey and San Pedro. Data are from Tables I and II.

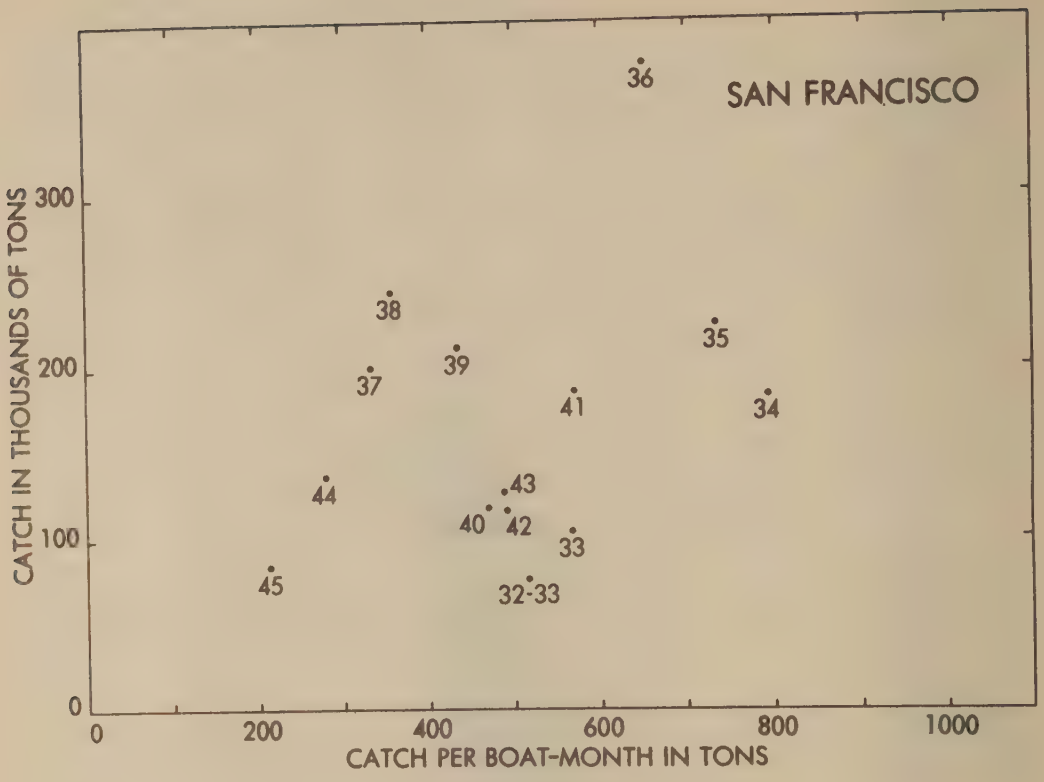

Fig. 3 Total catch plotted as a function of catch per boat-month at San Francisco Data are from Tables I and II.

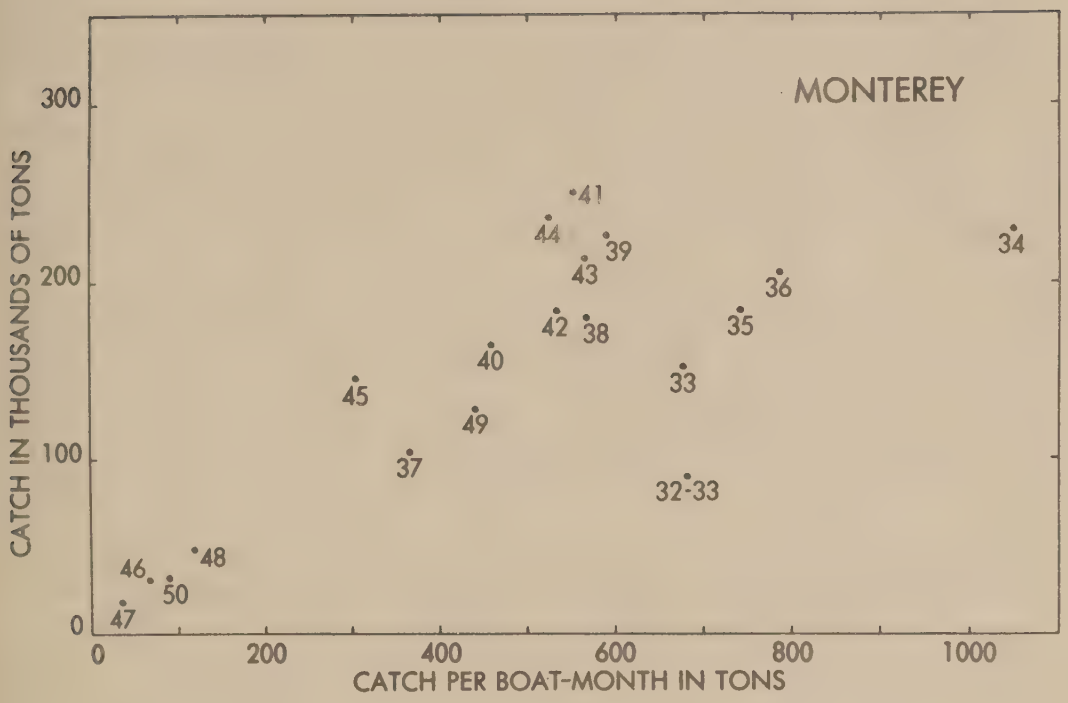

Fig. 4 Total catch plotted as a function of catch per boat-month at Monterey. Data are from Tables I and II.

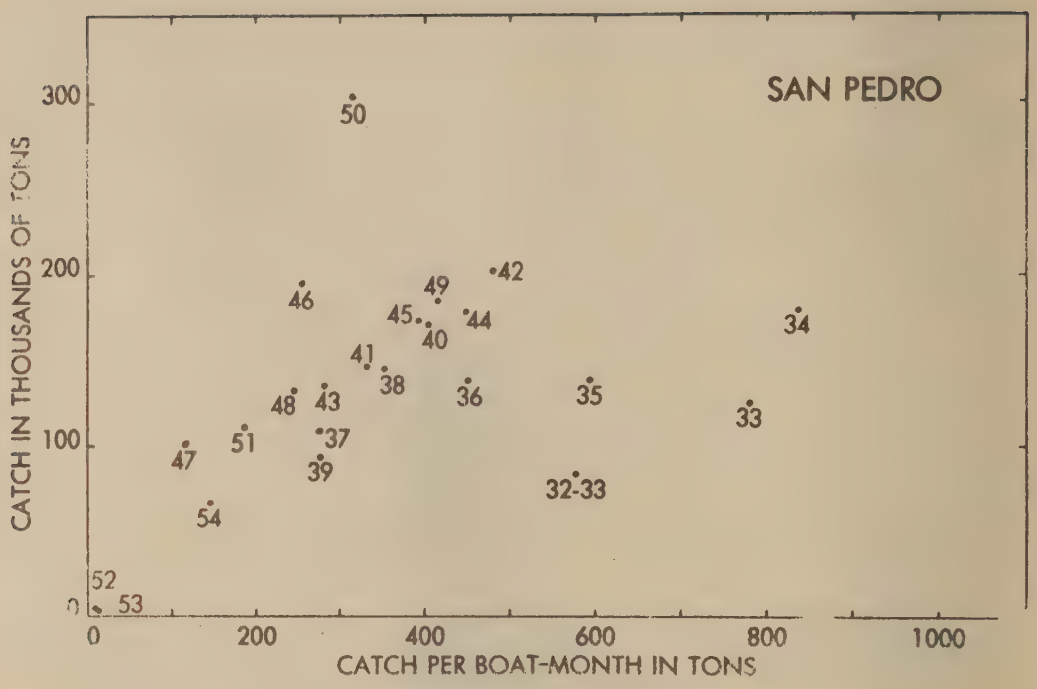

Fig. 2. Total catch plotted as a function of catch per boat-month at San Pedro. Data are from Tables I and II.

Catch per unit-of-effort at San Pedro follows the initial trend already described for San Francisco and Monterey. It rose to an all-time high in the 1934-35 season, and then fell to about 33 per cent of that value in the 1937-38 season. This was followed by an increase to about 50 per cent of the high value, about which there were fluctuations until the 1945-46 season. A decline to about 25 per cent of the previous level occurred in the 1947-48 season, followed by a return to the middling level in the 1949-50 season. Catch per unit-of-effort declined slightly in the 1950-51 season, but not below the level experienced in the late 1930's and early 1940's. The decline continued to an all-time low in the 1952-53 and 1953-54 seasons. Catch per unit-of-effort rose slightly in the 1954-55 season to about the level of the 1947-48 season.

Changes in catch per unit-of-effort at San Pedro tend to be associated with changes in total catch (Fig. 5). The association between changes in direction tends to be consistent over the period, except for the 1950-51 season. The association between relative magnitude of changes tends to be consistent following the first four seasons.

The general features of catch per unit-of-effort data at these three ports over the period 1932-33 through 1954-55 may be summarized as follows :

(a) the initial period is strikingly similar at all ports; catch per unit-of-effort rose to a peak in the 1934-35 season, and then fell by the 1937-38 season to 30 to 40 per cent of the 1934-35 value;

(b) the subsequent period differs between the three ports, especially at San Francisco. There the catch per unit-of-effort rose to almost 70 per cent of the 1934-35 value in the 1941-42 season and fell, following the 1943-44 season, to an all-time low in 1945-46, from which it did not recover. At Monterey, catch per unit-of-effort fluctuated around a level of 50 per cent of the 1934-35 value from 1938-39 through 1944-45, fell to a very low level in 1946-47 through 1948-49, rose to the previous middling level in 1949-50, and fell again in 1950-51. At San Pedro catch per unit-of-effort fluctuated around a level about 50 per cent of the 1934-35 value from 1938-39 through 1945-46 (a year later than at Monterey), fell to a low level in 1947-48, rose to the previous middling level in 1949-50 and 1950-51, fell to an all-time low in 1952-53 and 1953-54, and rose slightly in 1954-55;

(c) changes in catch per unit-of-effort and in total catch are not closely associated, if at all, at San Francisco. They tend to be rather closely associated at both Monterey and San Pedro with respect to magnitude and direction.

2.4 Amount of effort

The amount of effort expended in the California sardine fishery has not been measured directly. However, given data on total catch and catch per unit-of-effort, dividing the former by the latter will yield an indirect estimate of effort. This has been done by Clark and Daugherty (1952) and others. The data are included in Table II and shown in Fig. 2.

The variations in the amount of effort expended at the three ports have been mentioned in the previous section. Again, there is more similarity between San Pedro and Monterey than between those two ports and San Francisco. At the latter port, the amount of effort rose from 1932-33 to a high in 1938-39, declined to 1940-41, rose again in 1944-45, and fell slightly in 1945-46.

At Monterey, the amount of effort rose from 1932-33 to 1939-40 and tended to vary around the same level (or to increase slightly) until 1945-46, or perhaps 1947-48. It declined to 1949-50, and recovered to about the previous level in 1950-51.

At San Pedro, the amount of effort rose from 1932-33 to 1937-38 and tended to vary around the same level (or increase slightly) until 1945-46. It about doubled in 1946-47 and 1947-48, returned to the previous level in 1948-49 and 1949-50, and more than doubled in 1950-51.[7/] The amount of effort then declined to about the level of the early 1940's.

3 HISTORICAL RECORD - BIOLOGICAL DATA

3.1 Age data

Data on the age composition of the sardine catch in these fishing areas have been published for a considerable period of years by Felin et al. (1948, et seq.), Eckles (1954) and others. Wolf (in press) has added data for an earlier period and conveniently collected all age data in one source.

Several features of the age composition of the catch are of interest. Those considered here include :

(a) the average age of the catch;
(b) dominant age in the catch;
(c) number of year classes in the catch;
(d) the age at which each year class becomes fully recruited into the fishery; and
(e) average year class contributions by ages.

Other features relating to age composition will be considered in subsequent sections.

7/ Changes in the amount of effort, especially increases, in the order of 100 per cent do indeed seem unlikely in a highly mechanized fishery such as the California sardine fishery. These increases at San Pedro undoubtedly reflect, in large part, a shift of effort from Monterey and San Francisco to San Pedro (Table II). However, owing to the manner in which the effort data are derived, it is impossible to state how much of the apparent increase at San Pedro is real and how much may be an artifact. It is obvious that such increases in effort cannot be attributed solely to increases in the size of the fleet (Clark and Daugherty, 1950, and 1952).

3.1.1 Average age

Data on the average age of fish in the catch in the four areas are given in Table III and illustrated in Fig. 6.

Table III

AVERAGE AGE OF SARDINES IN THE CATCH, BY PORTS, FOR PERIOD OVER WHICH DATA ARE AVAILABLE 8/

Season	San Pedro	Monterey	San Francisco	British Columbia
1932-33	3.57	4.52	-	-
1933-34	4.56	4.90	-	-
1934-35	3.99	3.75	-	7.43
1935-36	3.04	3.53	-	7.50
1936-37	4.00	3.89	-	-
1937-38	3.12	3.12	-	-
1938-39	1.99	2.04	-	-
1939-40	2.36	2.42	-	5.69
1940-41	2.17	2.49	2.54	5.15
1941-42	2.29	2.23	2.65	3.96
1942-43	2.55	3.08	3.51	3.66
1943-44	2.56	3.24	3.92	4.65
1944-45	2.68	2.93	4.49	4.77
1945-46	2.72	3.11	3.54	5.16
1946-47	2.01	2.42	3.64	5.89
1947-48	2.34	1.89	1.33	6.49
1948-49	2.21	1.10	1.18	-
1949-50	2.54	2.46	2.61	-
1950-51	2.73	3.36	3.39	-
1951-52	3.26	3.58	-	-
1952-53	4.41	4.29	-	-
1953-54	4.21	-	-	-
1954-55	3.22	-	-	-
1955-56	3.39	-	-	-
1956-57	3.78	-	-	-
1957-58	3.33	-	-	-
1958-59	-	-	-	-
$\bar{X}$	3.04	3.07	2.98	5.49

8/ Data from sources indicated in Table I.

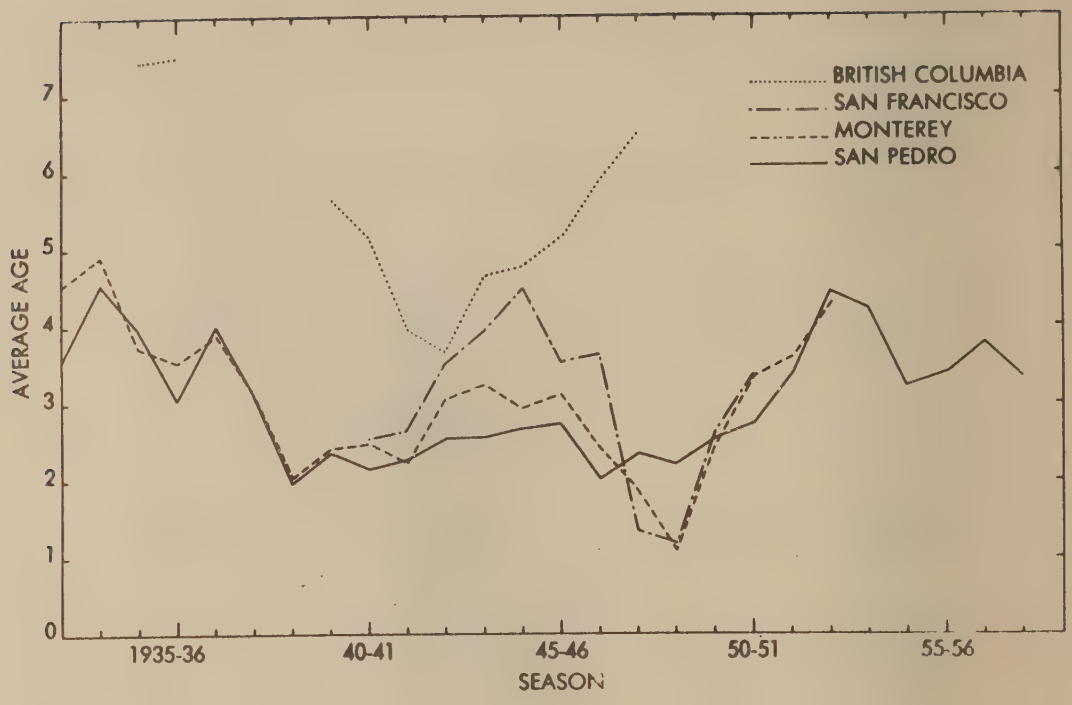

Fig. 6 Average age of fish in the British Columbia, San Francisco, Monterey and San Pedro sardine landings. Data are from Table III.

The average age of the fish in the catch may be influenced in several ways. When a dominant year class (one of above average size) enters the fishery, the average age of fish in the catch will decrease. As the dominant year class moves through the fishery, average age will increase. When a sub-dominant year class (one of below average size) enters the fishery, average age will increase. As the sub-dominant year class moves through the fishery, average age will decrease. Variations in age-specific or year class-specific availability will produce changes in average age appropriate to the nature of the change in availability. Changes in fishing mortality (to the extent that fishing mortality does not replace or is not replaced by natural mortality) will affect longevity and hence average age. A reduction in fishing mortality will act to increase average age and an increase in fishing mortality will act to reduce average age. Such effects would be most readily observed when there is a fairly large change in fishing mortality over a fairly long period of time. The effects on average age of fairly small between-season changes in fishing mortality would not be so apparent. Finally, if, for whatever reason, recruitment of younger year classes to the fished population ceases, average age will increase.

At California ports, and especially San Pedro, prior to about the early 1940's, it was noted that the "fall fish" were smaller in size than the "winter fish" (Clark, 1952, and others). In subsequent seasons, the "winter fish" tended to be present in reduced abundance or entirely absent. To the extent that these groups of fish represent fish of different age, as well as size, variations in their relative contributions to the catch would have an obvious effect on the average age of the fish in the catch. There is the possibility, however, that these groups represent fish characterized by different growth patterns, rather than by simple age differences (see 3.2.3).

Given information on average age of fish in the catch (Table III) and on age composition of the catch (Wolf, in press), the following explanation of secular changes in average age at the several ports may be inferred.

Data on average age of fish landed in British Columbia are available for the 1934-35, 1935-36, and 1939-40 through 1947-48 seasons (Fig. 6). In general, there is a decrease from about 7.5 years to 3.75 in the 1942-43 season, and an increase to about 6.5 in the 1947-48 season. The average of all seasons is about 5.5 years. The drop in average age from the first two seasons to the 1939-40 season was most probably caused by the presence in the earlier seasons of the apparently large 1927, 1928 and 1929 classes as nine-, eight- and seven-ring fish respectively (see 3.7). The decrease in average age from 1939-40 to 1942-43 was primarily a result of the entrance of the large 1939 class and perhaps secondarily to a greater than expected reduction in numbers of the 1936 and 1937 classes. The increase in average age from 1942-43 to 1947-48 had two causes: first, the passage of the 1939 class through the fishery and second, a succession of below average size year classes following the 1939 class until, finally, year classes subsequent to 1943 were represented negligibly or not at all.

Data on the average age of fish in the San Francisco landings are available from the 1940-41 through 1950-51 seasons (Fig. 6). Average age at San Francisco rose from about 2.5 years in 1940-41 to about 4.5 in 1944-45, fell to about 1.25 in 1948-49, and rose to not quite

3.5 in 1950-51. The average of all seasons is slightly below three years. (Data at San Francisco are for a shorter period than at the other California ports. Data for the earlier seasons would most likely raise the average age at San Francisco to a value intermediate to British Columbia and Monterey). The rise in average age from 1940-41 through 1944-45 was the result of the passage of the large 1939 class through the fishery. The drop from 1944-45 to 1945-46 was the result of the presence of the 1942 and 1943 classes. The 1946-47, 1947-48, and 1948-49 seasons were similar in that the younger year classes were under-available. However, in 1947-48 and 1948-49, the older year classes were absent; this accounts for the drop in average age in these two seasons. The rise from 1948-49 to 1950-51 was the result of a nearly normal representation of age classes in the catch and the progression of the 1947 class through the fishery.

Data on average age of fish in the Monterey landings are available from 1932-33 through 1952-53 (Fig. 6). Average age at Monterey rose from about 4.5 years in 1932-33 to almost 5 in 1933-34, fell to about 2 in 1938-39, rose to about 3.25 in 1943-44, fell to slightly more than 1 in 1948-49, and rose to about 4.25 in 1952-53. The average of all seasons is slightly above three years. The initial decline in average age at Monterey resulted from a reduction in the number of older year classes in the fishery, and the entrance of the 1931 and 1932 classes. The slight rise in 1936-37 was the result of the dominance of the 1932 class as four year old fish. The decline to 1938-39 was the result of the presence of the 1935 class and, especially, the 1936 and 1937 classes. The continued low average age to the 1941-42 season was the result of the presence of the large 1938 and 1939 classes. The rise to 1943-44 was the result of the passage of the 1939 class through the fishery. In 1944-45, the 1942 class was dominant and by 1945-46 the influence of the 1939 class was virtually ended. The decline to 1948-49 was a result of the under-availability of the older year classes and the presence of the 1945 and 1946 classes, although these were small year classes. The rise from 1948-49 to 1952-53 was caused by the passage of the 1947 class through the fishery, and the absence of any large, younger year classes.

Data on average age of fish in the San Pedro fishery are available from 1932-33 through 1957-58 (Fig. 6). The average age rose from about 3.5 in 1932-33 to 4.5 in 1933-34, fell to 3 in 1935-36, rose to 4 in 1936-37, fell to 2 in 1938-39, rose to 2.75 by 1945-46, fell to 2 in 1946-47, rose to about 4.5 by 1952-53, fell to 3.25 in 1954-55, rose to 3.75 in 1956-57 and returned to about 3.25 in 1957-58. The average of all seasons is slightly above three years. The increase from 1932-33 to 1933-34 was the result of the presence of the 1928 class and the presence of more older classes in the latter season. The decline to 1935-36 may be attributed to the presence of the 1932 class and a reduction in the number of older year classes. The passage of the 1932 class through the fishery accounts for the rise in 1936-37. The decline to 1938-39 is a result of the presence of the 1935 class and, especially, of the 1936 and 1937 classes. The ensuing long period of slight increase to 1945-46 was due to the presence of a series of several large year classes, including the 1937, 1938, 1939 and 1940 classes. Subsequent year classes were smaller, accounting for the slight increase in average age. The drop to 1946-47 resulted from the entrance of the 1945 class. The increase to 1952-53 was the result of the passage through the fishery of the 1945, 1946 and, in particular, the 1947 and 1948 classes. The slight rise in 1956-57 was caused by the presence of the 1952 class, and the absence of the large, younger year classes.

It is obvious that the changes in average age of fish in the catch may be attributed primarily to variations in the size of year classes passing through the fishery (and in British Columbia to the lack of new year classes in the terminal years of the fishery there), and secondarily to variations in availability. However, over this same period there have been rather large changes in fishing intensity, and some of these have been in the nature of secular trends. It was earlier stated that changes in effort would affect average age, especially when effort changes occurred in the form of secular trends. Can such effects be observed in these data?

The relationship between average age (Table III) and amount of effort (Table II) for San Francisco, Monterey and San Pedro, is shown in Fig. 7. The relationship for San Francisco is not significant ($r = +0.55$, $P > 0.10$); i.e. it does not differ significantly from zero. The relationship at Monterey is significant ($r = -0.62$, $P < 0.01$), and may be described (least squares fit) by the rectilinear regression equation $Y = 5.11 - 0.00640X$, where Y is average age and X is amount of effort. (The customary convention is followed throughout, where Y represents the dependent variable and X the independent variable). The relationship at San Pedro is significant ($r = -0.49$, $0.05 > P > 0.01$), and may be described by the equation $Y = 3.85 - 0.00198X$. 9/

In other words, about 38 per cent of the changes in average age at Monterey, and about 24 per cent of the changes at San Pedro may be attributed to changes in the amount of effort. The same relationship did not obtain at San Francisco 10/. The residual variations in average age not explained by the relationship between average age and effort (i.e. the deviations of the observed average age from the calculated average age from the regression equations) are shown in Figs. 8 and 9 for Monterey and San Pedro respectively. The changes in these residual deviation curves correspond rather well with the changes in direction (but not level) of the observed average age curves. The original explanations given for these changes apply (see 3.1.1.).

9/ In the San Pedro regression, the seasons 1946-47, 1947-48, and 1950-51 are those in which effort was calculated to be about 200 per cent that of adjacent seasons. Reservations about changes of this magnitude have already been expressed (footnote 7). However, it should be noted that the true relationship between average age and amount of effort may not be rectilinear. For example, it can be shown that the relationship between average age and total annual mortality rate (in a hypothetical population) is described by one branch of an equilateral hyperbola referred to its asymptotes as axes. If natural mortality rate is constant and fishing mortality rate (and hence total mortality rate) proportional to effort (Widrig, 1954), the relationship between average age and effort may be best described by a hyperbola.

10/ The data examined for San Francisco include only six pairs of observations and do not include the period of greatest change in effort. However, if average standard length is used as a substitute for average age (a reasonable substitution), the series is extended to include 11 pairs of observations and the period of greatest change in effort. The relationship is still not significant.

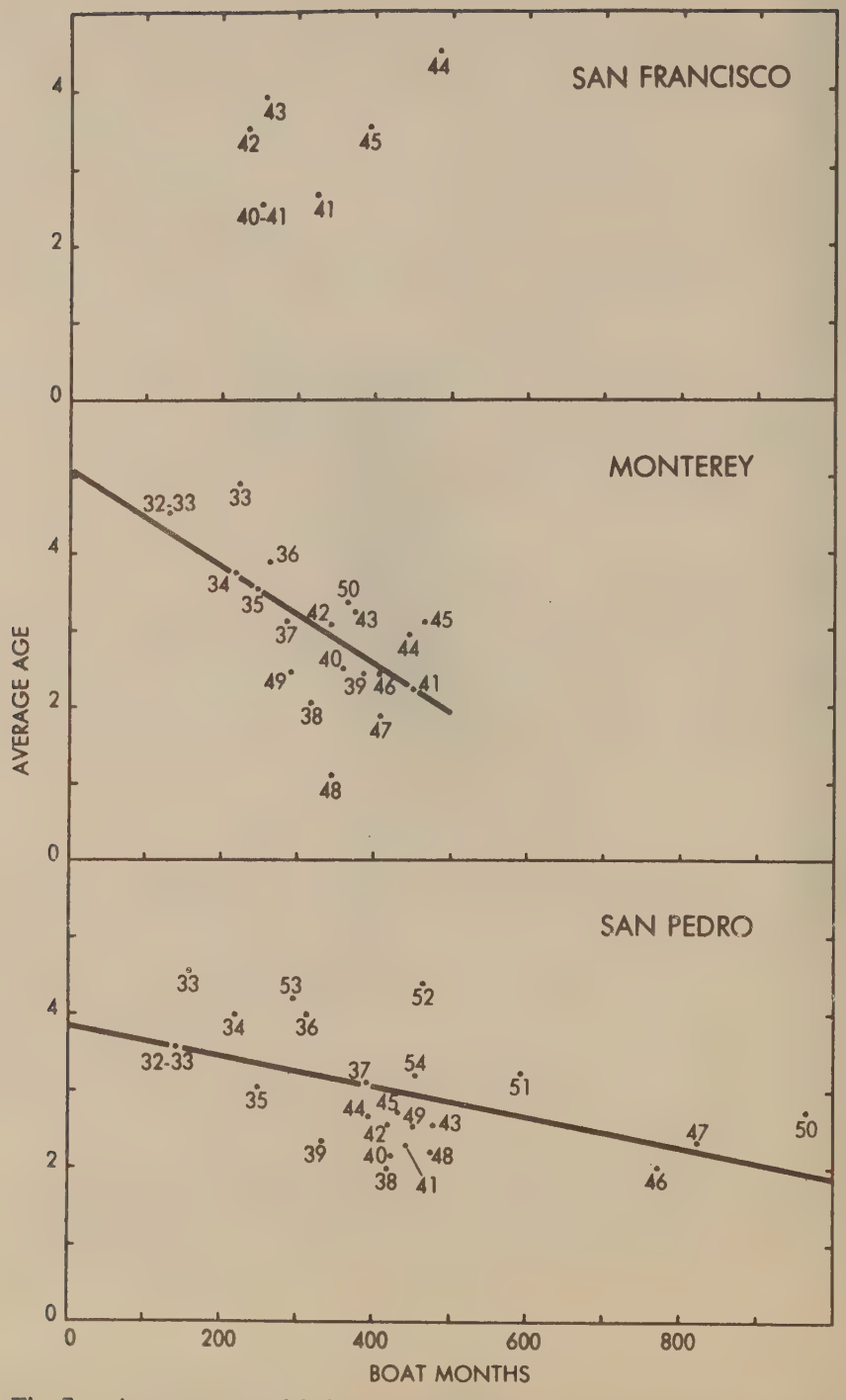

Fig. 7 **Average age of fish in the sardine catch plotted as a function of the amount of effort, for San Francisco, Monterey and San Pedro. Data are from Tables II and III.**

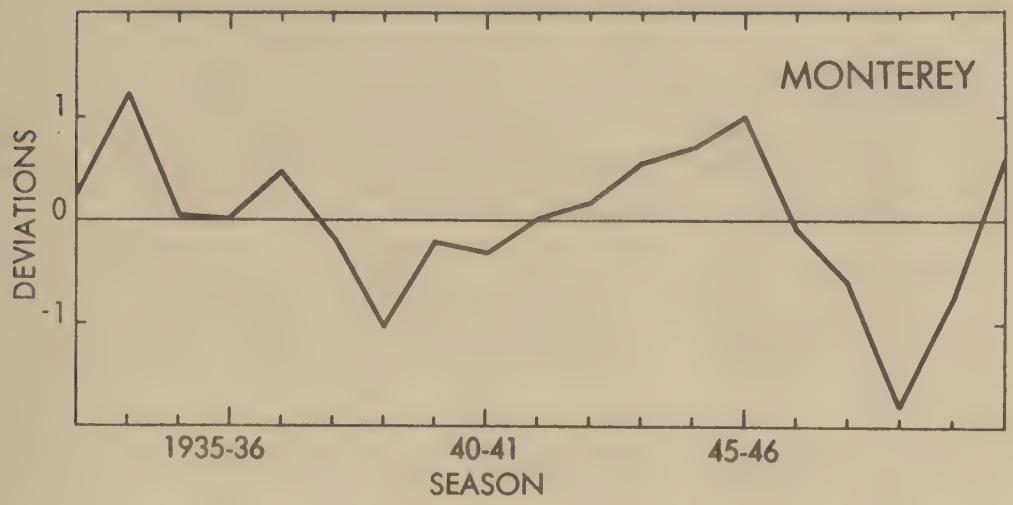

Fig. 8 Deviations, at Monterey, of observed values of average age from those predicted from amount of effort (regression of Fig. 7).

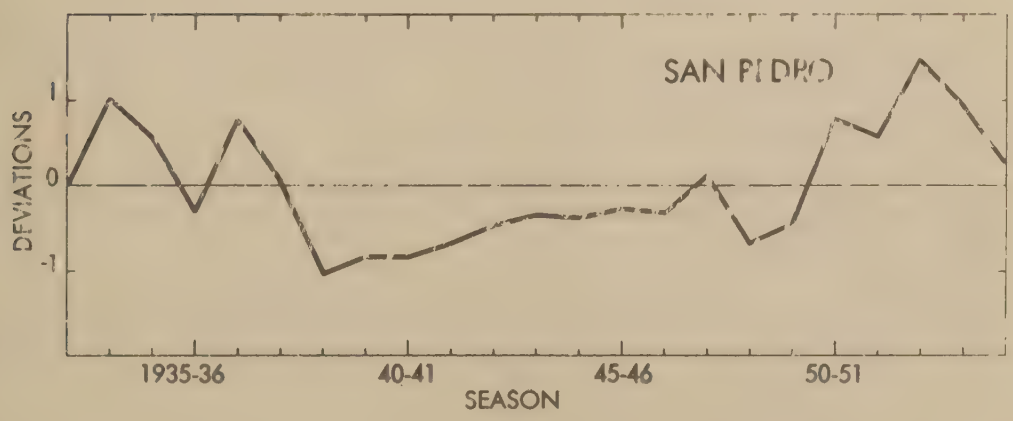

Fig. 9 Deviations, at San Pedro, of observed values of average age from those predicted from amount of effort (regression of Fig. 7).

The main features of these average age data include the following:

(a) the average ages over the periods for which data are available were 5.49 years at British Columbia, 2.98 at San Francisco, 3.07 at Monterey, and 3.04 at San Pedro. Data over the entire period at San Francisco would most likely raise the average age there to a value intermediate to British Columbia and Monterey;

(b) the general trends in average age in the four areas are quite similar. There is a decline in average age from the early to late 1930's, a rise from the early to mid-1940's, a decline to the late 1940's, a rise to approximately the early 1930 level in the early 1950's, and a subsequent maintenance of this level. The mid-1940 rise and late 1940 decline were much less pronounced at San Pedro than at Monterey and San Francisco;

(c) the changes in average age may be attributed to the passage through the fishery of year classes of different magnitudes and, to a lesser extent, to changes in availability. In addition, at British Columbia the terminal increase in average age may be attributed to the lack of new year classes entering the fishery;

(d) there is, however, an underlying negative relationship between average age and amount of effort; as effort increases average age decreases. Although this relationship was not apparent at San Francisco, it accounted for a fraction of the changes in average age at Monterey (38 per cent) and San Pedro (24 per cent). The residual deviations in average age may be accounted for by changes in year class size and availability.

3.1.2 Dominant age

Data on the dominant age of fish in the catch are given in Table IV and shown in Figs. 10 and 11. It is to be expected that there is a close relationship between the dominant age represented in the catch and the average age of fish in the catch. Comparison of Fig. 10 with Fig. 6 demonstrates that the relationship is indeed close.

The data on dominant ages in the catch, in the form of frequency distributions, are shown by area in Fig. 11. The dominant age at British Columbia has ranged from three to seven, no single age being outstandingly frequent. The dominant age at San Francisco has ranged from one to five. Age three has been dominant most frequently, but not much more so than ages one and two. The dominant age at Monterey has ranged from one to four. Ages two and three have been dominant most frequently, but, again, not much more so than ages one and four. The dominant age at San Pedro has ranged from one to five. Age two has been dominant most frequently, the only instance of any single age being rather consistently dominant.

Three other features of the frequency distributions of dominant ages are of interest. First, even though average age tends to increase from south to north, age one has been dominant more frequently at Monterey and San Francisco than it has at San Pedro. Second, the

Table IV

NUMBER OF YEAR CLASSES AND DOMINANT AGES OF SARDINES IN THE CATCH, BY PORTS, FOR PERIOD OVER WHICH DATA ARE AVAILABLE [11]

Season	San Pedro		Monterey		San Francisco		British Columbia	
	Number of y.c.	Dominant age	Number of y.c.	Dominant age	Number of y.c.	Dominant age	Number of y.c.	Dominant age
1932-33	9 12/	3	12 12/	4	-	-	-	-
1933-34	13 12/	5	13 12/	4	-	-	-	-
1934-35	13 12/	3	13 12/	3	-	-	11 12/	6
1935-36	6	3	8	3	-	-	11 12/	7
1936-37	6	4	9	4	-	-	-	-
1937-38	9	2	10	2	-	-	-	-
1938-39	9 12/	2	10 12/	1	-	-	-	-
1939-40	6 12/	2	11 12/	2	-	-	11	5
1940-41	6 12/	2	9 12/	2	11	3	10	4
1941-42	7	2	7	2	8	2	10	4
1942-43	7	2	7	3	8	3	10	3
1943-44	7	2	9	4	8	4	10	4
1944-45	8	3	8	2	8	5	10	5
1945-46	8	2	8	3	9	3	9	6
1946-47	9	1	9	1	9	1	6	7
1947-48	9	2	8	1	6	1	8	7
1948-49	6	2	6	1	6	1	-	-
1949-50	7	2	8	2	7	2	-	-
1950-51	5	2	8	3	5	3	-	-
1951-52	8	3	7	3	-	-	-	-
1952-53	6	4	6	4	-	-	-	-
1953-54	8	5	-	-	-	-	-	-
1954-55	8	3	-	-	-	-	-	-
1955-56	9	3	-	-	-	-	-	-
1956-57	8	4	-	-	-	-	-	-
1957-58	10	3	-	-	-	-	-	-
13/								
Σ =	206	71	192	54	85	28	108	58
N =	26	26	21	21	11	11	11	11
$\bar{X}$ =	8.01	2.73	9.14	2.57	7.73	2.54	9.82	5.27

11/ Data from sources indicated in Table I.
12/ One or more additional year classes present.
13/ One added to items referred to in footnote 11.

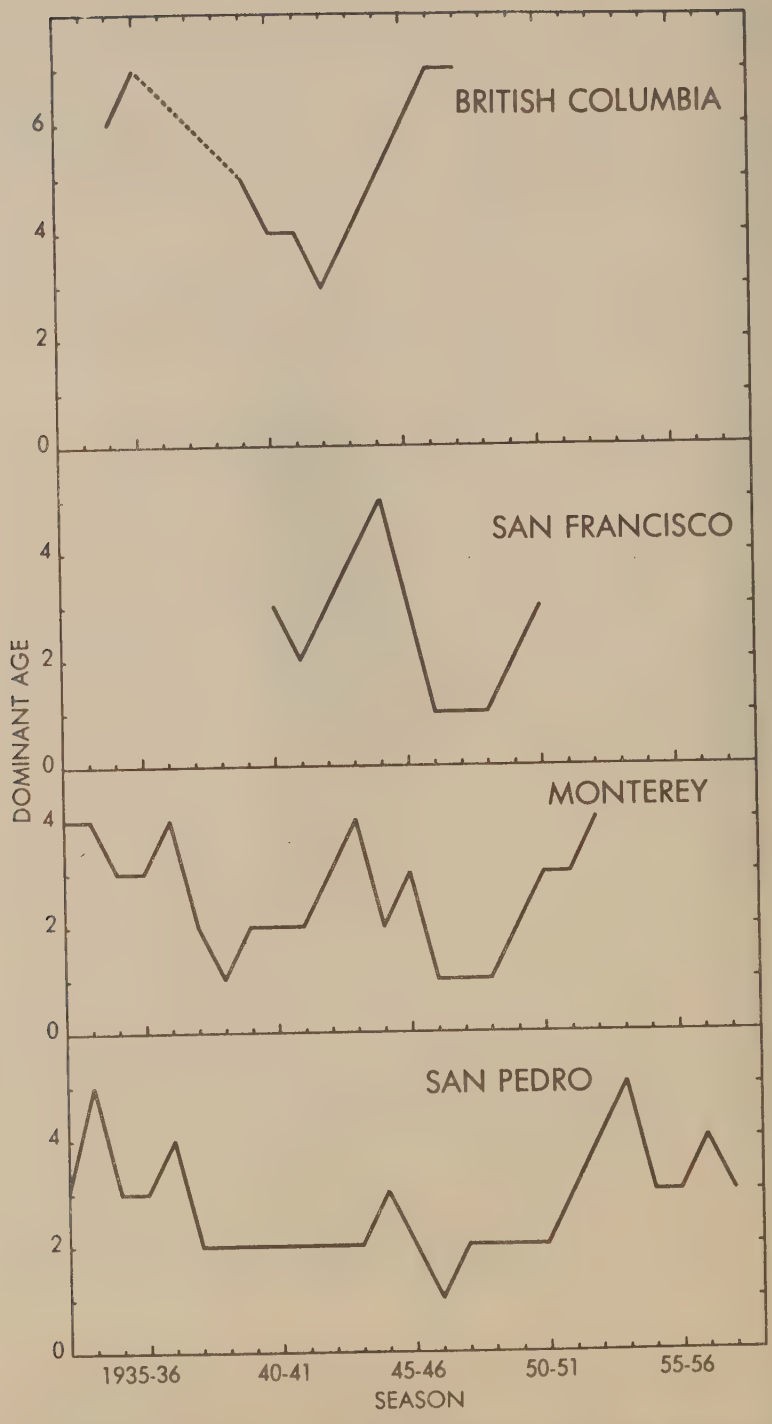

Fig. 10 Dominant age of fish in the sardine catch at British Columbia, San Francisco, Monterey and San Pedro. Data are from Table IV.

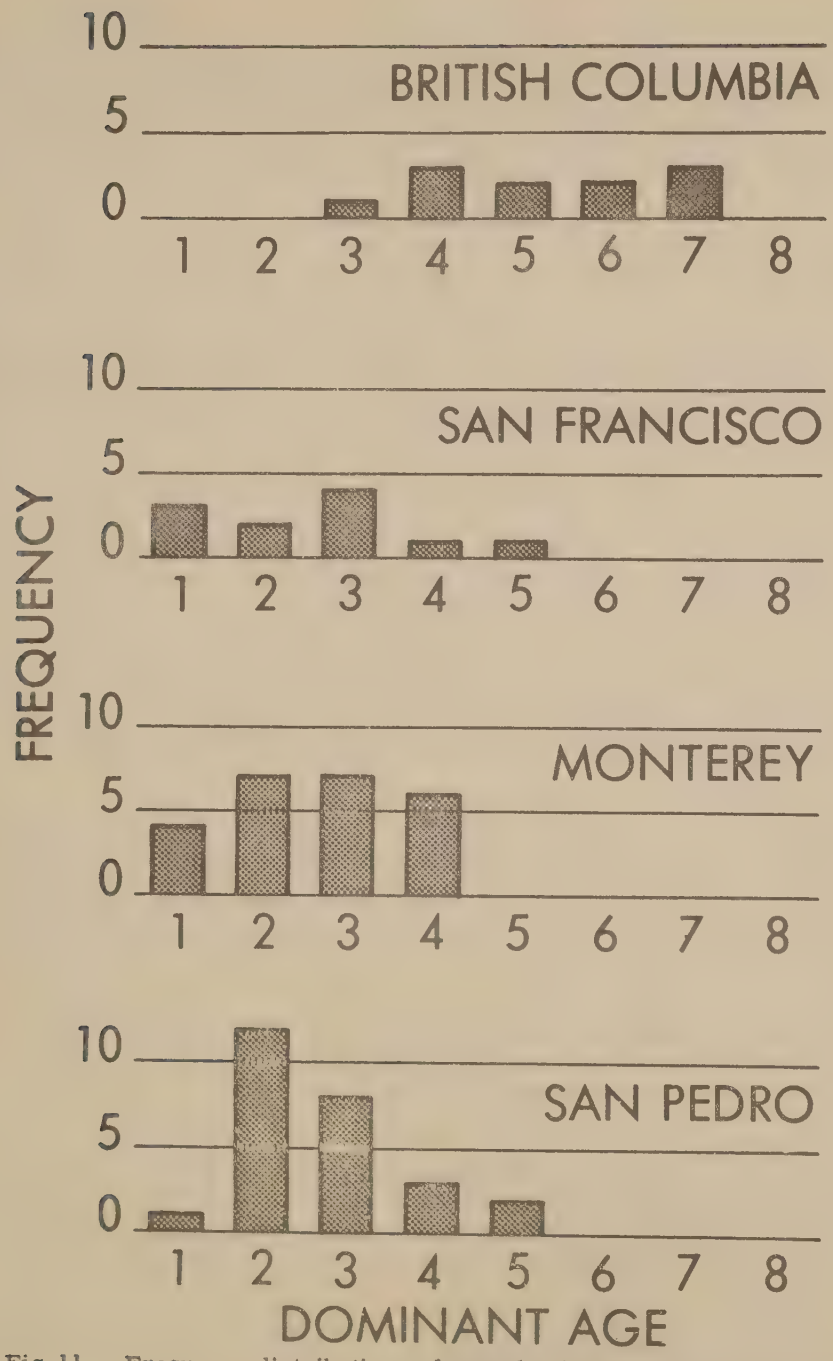

Fig. 11 Frequency distributions of ages dominant in the sardine catch at British Columbia, San Francisco, Monterey and San Pedro. Data are from Table IV.

high percentage dominance of ages three and four at Monterey is unique. Third, while the distribution at San Pedro is quite skewed, the distributions at the other ports are extreme examples of platykurtosis. Some or all of these features may be related to the geographic origin of the year classes. This possibility will be considered later (see 5.4).

3.1.3 Number of year classes in catch

Data on the number of year classes in the catch are given in Table IV and shown in Figs. 12 and 13.

As the dominant age in the catch is related in a general way to the average age of fish in the catch, so too is the number of year classes in the catch. It is to be expected that as fishing intensity increases and average age decreases, the number of year classes in the catch will also decrease. In general, this relationship obtains in the sardine data.

The average number of year classes in the catch in British Columbia over the period for which there are data was 9.82. Their number decreased from 12 in 1934-35 to 10 in 1940-41. This level was maintained until 1944-45, and was followed by a drop to six in 1946-47 and to eight in 1947-48. The terminal decrease in number of year classes is, of course, a reflection of the failure of the younger year classes to enter the British Columbia fishery during its last years.

The average number of year classes in the catch at San Francisco was 7.73. (Had data for the earlier seasons been available, the average would undoubtedly have been higher.) Their number declined somewhat regularly, with the exception of one four-season period of constant number, from 11 in 1940-41 to five in 1950-51.

The average number of year classes in the catch at Monterey was 9.14. Their number tended to decline during the first half of the period and to fluctuate around a level during the latter half of the period. The number of year classes declined from 13 in 1932-33 to eight in 1935-36, rose to 12 in 1939-40, and declined to seven in 1941-42. Thereafter the number of year classes tended to fluctuate around an average level slightly greater than seven, with fluctuations as great as nine and six. There were six year classes in the 1952-53 season.

The average number of year classes in the catch at San Pedro was 8.01. Their number tended to decline during the first part of the period, to fluctuate around a level during the middle part of the period, and to rise during the terminal part of the period. The number of year classes rose from nine in 1932-33 to 14 in 1933-34, declined to six in 1935-36 (when a decline also occurred at Monterey), rose to ten in 1938-39, and declined to seven in 1939-40. Thereafter the number of year classes tended to fluctuate around this level until 1952-53, or perhaps even 1956-57, with fluctuations as great as nine and five. Starting in 1952-53 there was a more or less gradual rise to ten year classes in 1957-58. If, as seems likely, this rise is associated with a decrease in effort, it somewhat lags the rise in average age.

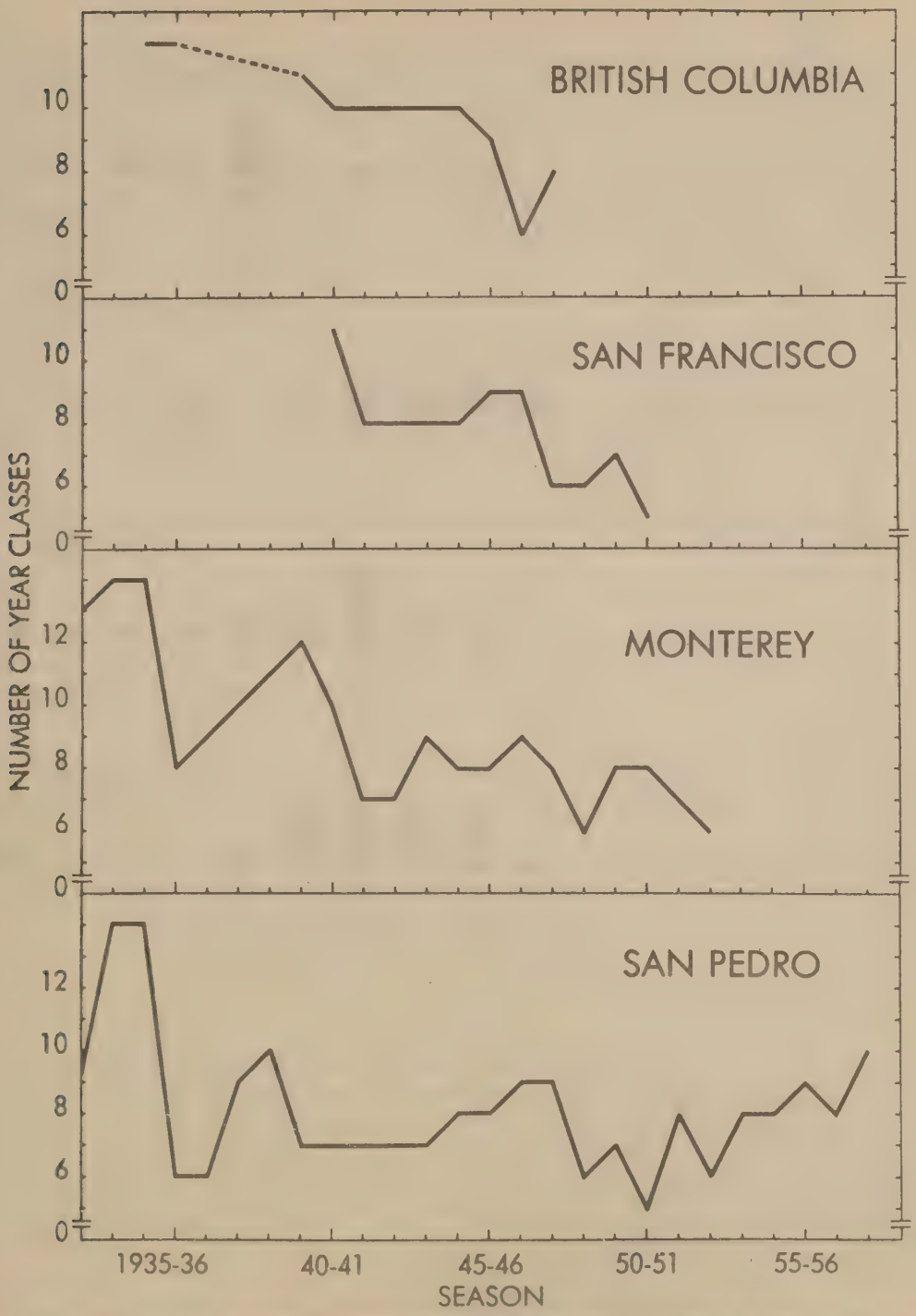

Fig. 12 Number of year classes present in the sardine catch at British Columbia, San Francisco, Monterey and San Pedro. Data are from Table IV

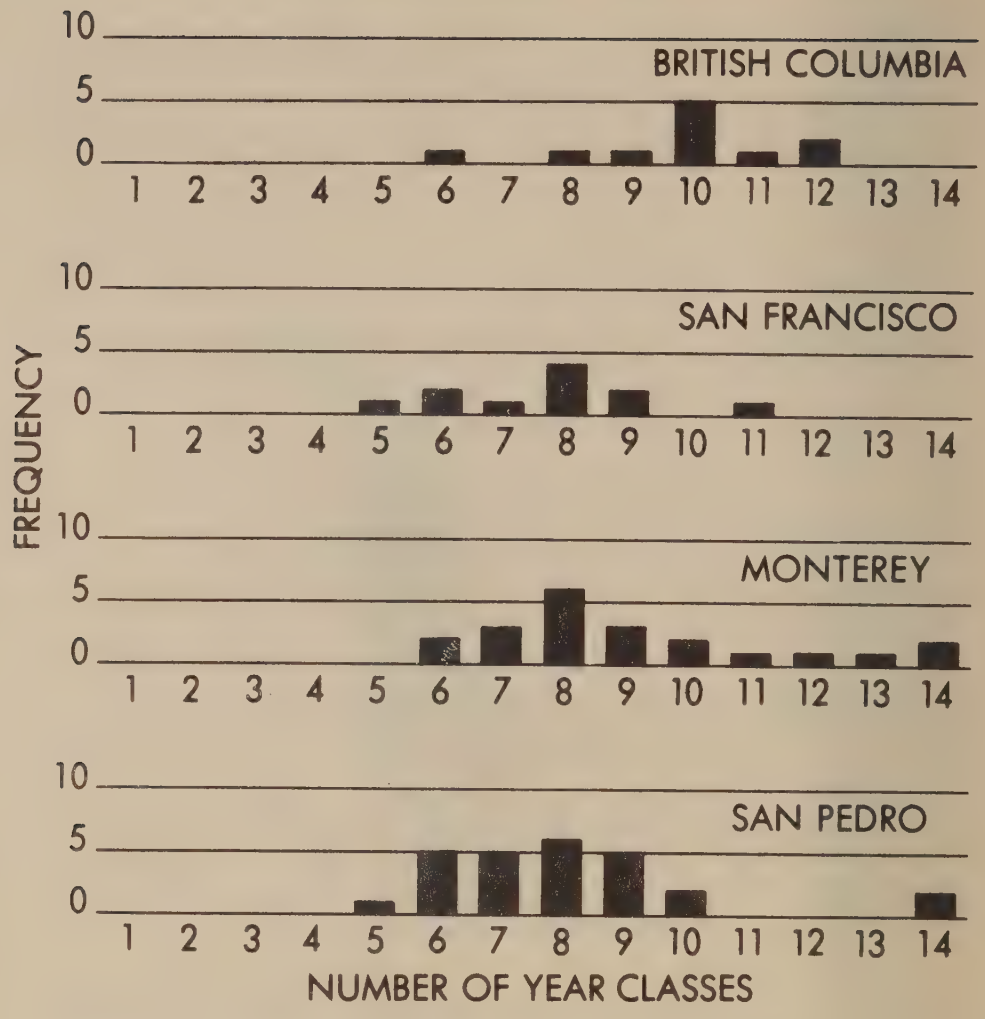

Fig. 13 Frequency distributions of number of year classes in the sardine catch at British Columbia, San Francisco, Monterey and San Pedro. Data are from Table IV.

The frequency distributions of the number of year classes in the fishery in the four areas are shown in Fig. 13. Although the average at British Columbia is the highest it is not as great as might be expected, owing to the less frequent presence there of the younger year classes. The data for San Francisco are not strictly comparable, since they are not available for the earlier years. The distributions for Monterey and San Pedro are both skewed; in some seasons the number of year classes in the catch exceeded those at the other two ports. Aside from the skewness, the distribution for Monterey is not kurtotic, while that for San Pedro tends to be platykurtic.

3.1.4 Age at full recruitment

The use of catch curves in ascertaining the age at full recruitment of a year class (or age class) into a fishery has been discussed by Marr (1953), and especially by Ricker (1958a). Year class catch curves, by ports, were used to determine the ages at which each sardine year class became fully recruited at each port. The criterion used was the age at which a given year class contributed the greatest number of individuals to the catch at a given port. The advantage of this criterion is that it can be applied objectively. A possible disadvantage is that the year class may not actually be fully available until the next older age, as may be inferred from the slope of the right limb of the catch curve. Determination on this latter basis is more subjective, owing to possible variations in availability, among other things. The criterion used then may have occasionally resulted in the selection of an age at full recruitment too young by one year.

Data on age at full recruitment are given in Table V and shown in Figs. 14 and 15.

The average age at full recruitment in British Columbia was 4.67 for the 1932 through 1943 classes. Age at full recruitment in British Columbia (Fig. 14) declined more or less steadily from eight for the 1932 class to two years for the 1943 class. The final level corresponds to that obtaining at the California ports. A consistent decline in age at full recruitment occurred only in British Columbia. Such a decline could arise from several causes, including :

(a) a continuing northward shift in spawning grounds could result in fish being recruited to the British Columbia fishery at earlier ages. It is known that spawning occurred in the Pacific Northwest in 1939. It is not known if a trend in location of spawning grounds existed, although this was a period of relatively high surface temperatures (see 5.4).

(b) a change in migratory habits could result in more younger and fewer older fish entering the British Columbia fishery. While there is evidence for some changes in migrations, there is none for such differential changes;

(c) a high total mortality rate would reduce the average age of fish in the population, and result in more effort directed to catching younger fish. A high total mortality rate is, of course, a combination of rates resulting from fishing and natural causes. While definitive evidence is lacking to enable a choice between these three or more alternatives, or between the two sources of mortality, the relatively high intensity of the fishery during this period (Clark and Marr, 1955) could have been the cause of the change.

Table V

AGE AT WHICH EACH SARDINE YEAR CLASS WAS FULLY RECRUITED INTO THE FISHERY AT THE SEVERAL PORTS [14/]

Year class	British Columbia	San Francisco	Monterey	San Pedro
1929	-	-	4	-
1930	-	-	4	4
1931	-	-	3	3
1932	8	-	3	3
1933	7	-	3	4
1934	6	-	2	3
1935	6	-	2	2
1936	5	-	3	2
1937	4	-	1	1
1938	5	3	3	2
1939	4	2	2	2
1940	4	3	3	2
1941	3	4	3	3
1942	2	3	2	2
1943	2	2	2	2
1944	-	1	1	2
1945	-	4	1	1
1946	-	3	3	2
1947	-	2	2	3
1948	-	-	3	2
1949	-	-	-	2
1950	-	-	-	4
1951	-	-	-	3
1952	-	-	-	3
1953	-	-	-	2
Σ =	56	27	50	59
N =	12	10	20	24
$\bar{X}$ =	4.67	2.70	2.50	2.46

14/ Data from sources indicated in Table I.

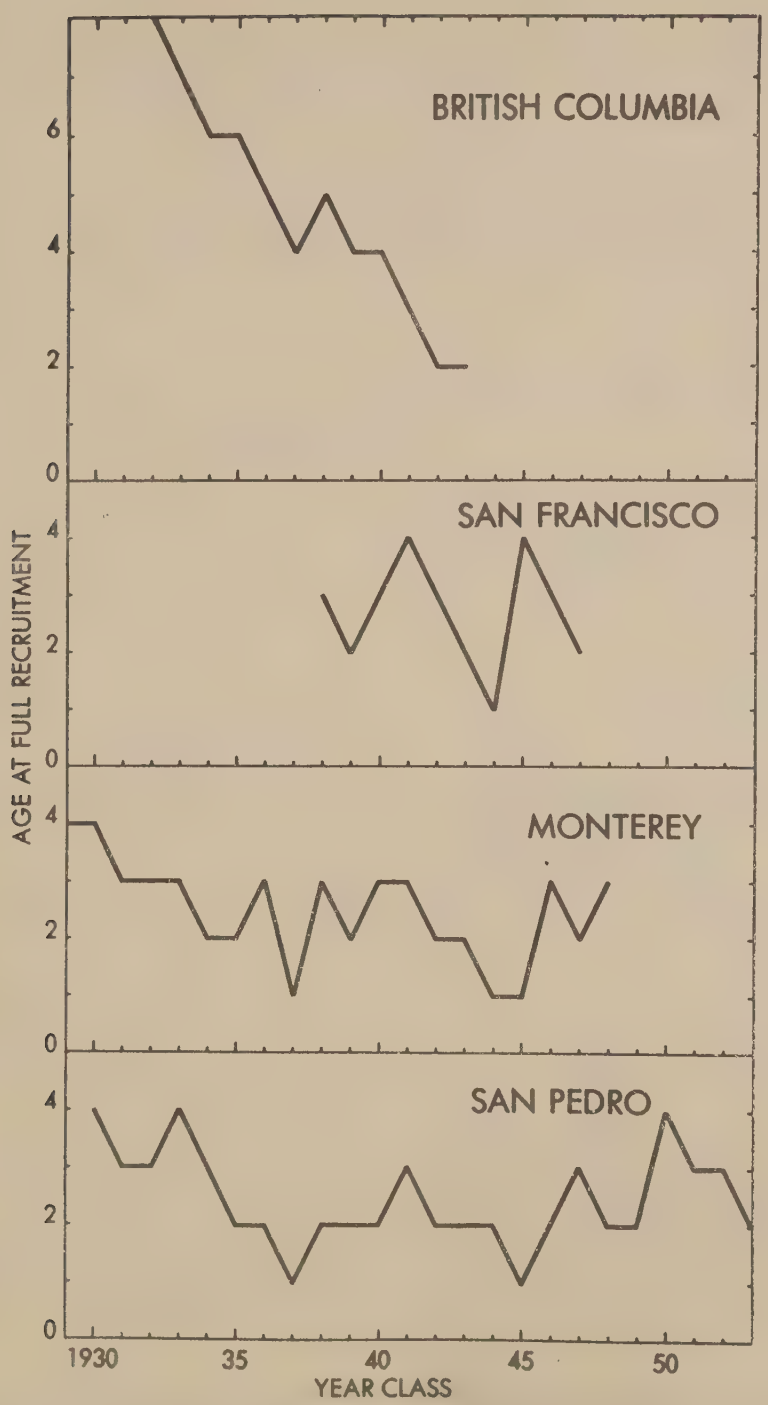

Fig. 14 Age at which each year class was fully recruited into the sardine fishery at British Columbia, San Francisco, Monterey and San Pedro. Data are from Table V.

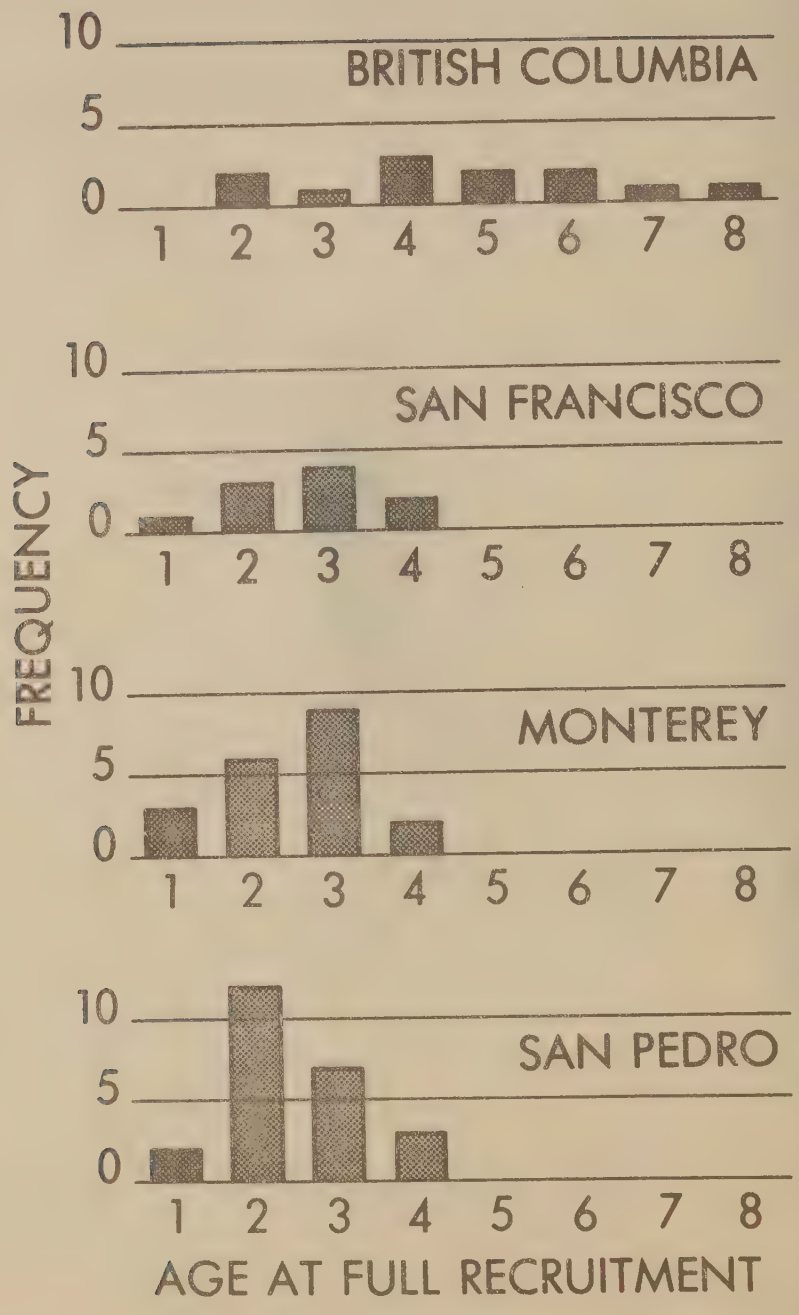

Fig. 15 Frequency distributions of ages at which year classes were fully recruited into the sardine fishery at British Columbia, San Francisco, Monterey and San Pedro. Data are from Table V.

The average age at full recruitment at San Francisco was 2.70 for the 1938 through 1947 classes. Age at full recruitment (Fig. 14) for these year classes varied from one to four years and showed no trend over the period covered.

The average age at full recruitment at Monterey was 2.50 for the 1929 through 1948 classes. Age at full recruitment at Monterey (Fig. 14) declined from four years for the 1929 class to two years for the 1934 class. Thereafter it varied between two and three years, except for the 1937, 1944 and 1945 classes which were fully recruited at one year of age.

The average age at full recruitment at San Pedro was 2.46 for the 1930 through 1953 classes. Age at full recruitment (Fig. 14) declined from four years for the 1930 class to two years for the 1935 class. It was remarkably consistent at two years through the 1946 class, except for the 1937 and 1945 classes which were fully recruited at age one (as they were at Monterey) and the 1941 class which was fully recruited at age three. The age at full recruitment for the 1947 through 1953 classes varied at a somewhat higher level, similar to that of the initial period, between two and four years.

The frequency distributions of the ages at which the year classes were fully recruited at the several ports are shown in Fig. 15. The distribution for British Columbia appears to be extremely platykurtic, but small numbers may make it impossible to recognize the true shape. While four is the most common age at full recruitment, it is only slightly more so than a number of other ages.

The frequency distribution for San Francisco is more symmetrical, although slightly skewed. Three is the most common age at full recruitment, but only slightly more so than two and four.

The frequency distribution for Monterey is similar to that for San Francisco, but here three is without question the commonest age at full recruitment, followed by two, one and four in that order.

The frequency distribution for San Pedro is also skewed, but in the opposite direction from the distributions for Monterey and San Francisco. Two is the dominant age at full recruitment, one half the year classes at San Pedro having been fully recruited at that age.

As would be expected, the frequency distributions shown in Fig. 15 bear a strong resemblance to those in Fig. 11 of dominant ages in the catch. That they do not coincide exactly is accounted for by differences in year class size; a dominant year class may contribute more fish (and thus be the dominant age class) at one or even two years past full recruitment, than will a subdominant year class at the age of full recruitment.

Although the data on age at full recruitment do not include the same year classes at all ports, the general features of these data may be summarized as follows :

(a) average age at full recruitment was about 4.7 at British Columbia, 2.7 at San Francisco, 2.5 at Monterey, and 2.5 at San Pedro;

(b) age at full recruitment declined rather consistently and markedly at British Columbia, exhibited no trend at San Francisco, declined initially at Monterey and thereafter showed no trend, declined initially at San Pedro, was remarkably consistent during an intermediate period and rose during the final period;

(c) an age at full recruitment of two years was clearly dominant at San Pedro. Progressing northward there was a tendency for age at full recruitment to increase with a decreasing tendency for any single age to be dominant.

3.1.5 Average year class contribution by ages

Having considered average age, dominant age, number of year classes and age at full recruitment, it is of interest also to note the average percentage contribution by ages that a year class makes at each port. Such data will also be of use subsequently in estimating the sizes of year classes for which there are only incomplete age data.

The data are given in Table VI and shown in Fig. 16. The data for San Pedro and Monterey, based on 18 and 17 year classes respectively, are more reliable than those for San Francisco and British Columbia which are based on six and two year classes respectively.

Table VI

AVERAGE PERCENTAGE CONTRIBUTION BY AGES OF SARDINE YEAR CLASSES AT THE SEVERAL PORTS [15/]

Port	Age (rings)										
	0	1	2	3	4	5	6	7	8	9	10
British Columbia	-	-	0.08	11.48	32.74	26.80	20.92	6.76	1.20	0.06	0.01
San Francisco	-	9.60	34.07	26.82	17.24	9.43	2.78	0.02	-	0.03	-
Monterey	0.04	15.64	29.27	27.74	16.70	7.09	2.63	0.65	0.20	0.03	-
San Pedro	0.11	12.41	39.20	29.97	12.33	4.24	1.34	0.36	0.04	-	-

15/ Percentages for British Columbia based on the 1937 and 1938 classes, for San Francisco on the 1939 through 1944 classes, for Monterey on the 1930 through 1946 classes, and for San Pedro on the 1931 through 1948 classes. Data from sources indicated in Table I.

Obviously, the curves for Monterey and San Francisco bear more resemblance to the curve for San Pedro than to that for British Columbia. Year classes make their greatest contributions at ages two and three at San Pedro, and ages four, five and six in British Columbia.

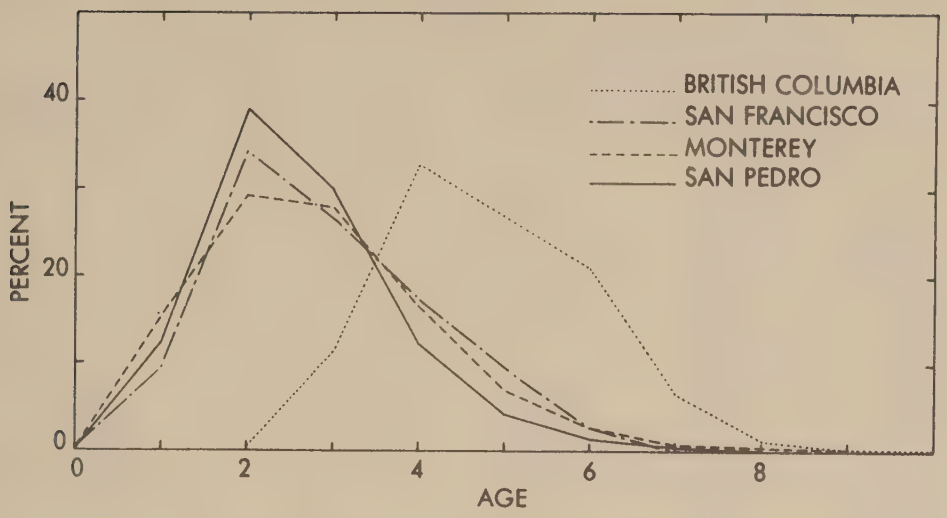

Fig. 16 **Average percentage contribution by ages of year classes at British Columbia (based on two year classes), San Francisco (six), Monterey (17) and San Pedro (18). Data are from Table VI.**

3.2 Length data

Various kinds of length data on the fish landed at the several ports are available from a number of published and unpublished sources. Of particular interest are data on :

(a) average standard length of fish in the catch, by ports and seasons;

(b) average standard length, by year classes and ports, at the end of the first year of life;

(c) growth (length-on-age curves) by ports, and

(d) growth, by seasons and ports.

3.2.1 Average length

Data on average standard length of fish landed in the four areas, by season, are given in Table VII and shown in Fig. 17. The mean average lengths over the periods for which data are available are 243.0 mm in British Columbia, 217.4 mm at San Francisco, 212.8 mm at Monterey, and 211.9 mm at San Pedro.

Table VII

AVERAGE SIZE (STANDARD LENGTH) OF SARDINES IN THE CATCH, BY AREA, FOR PERIOD OVER WHICH DATA ARE AVAILABLE 16/

Season	San Pedro	Monterey	San Francisco	British Columbia
1924-25	213.2	220.5	-	-
1925-26	209.6	219.2	-	-
1926-27	223.4	215.9	-	-
1927-28	223.7	218.6	-	-
1928-29	218.9	227.6	-	-
1929-30	214.7	218.9	-	250.8
1930-31	220.1	216.5	-	249.2
1931-32	221.2	219.7	-	244.0
1932-33	227.9	228.7	-	246.7
1933-34	225.5	229.8	-	246.7
1934-35	221.9	223.3	-	251.1
1935-36	221.1	219.9	229.5	253.1
1936-37	223.5	218.5	221.9	232.2
1937-38	205.1	209.6	220.8	251.2
1938-39	192.7	192.0	200.6	249.3
1939-40	198.4	201.0	204.6	243.8
1940-41	196.0	204.1	199.6	239.3
1941-42	194.9	195.2	203.7	222.5
1942.43	199.7	211.6	218.1	222.3
1943-44	199.2	212.4	225.9	236.7
1944-45	204.0	212.3	234.7	237.3
1945-46	202.8	215.9	224.6	240.4
1946-47	203.2	202.1	222.5	248.8
1947-48	202.7	196.9	-	250 8
1948-49	200.2	177.9	-	-
1949-50	201.3	208.4	213.6	-
1950-51	212.2	222.6	222.9	-
1951-52	212.4	219.8	-	-
1952-53	234.3	-	-	-
1953-54	222.6	-	-	-
1954-55	204.5	213.6	-	-
1955-56	214.3	-	-	-
1956-57	225.5	-	-	-
1957-58	214.5	-	-	-
Σ =	7205.2	6172.5	3043.0	4616.2
N =	34	29	14	19
$\bar{X}$ =	211.9	212.8	217.4	243.0

16/ Data from the following sources : British Columbia: 1929-30, 1932-34, 1936-38, unpublished data from J.L. Hart, Fisheries Research Board of Canada; 1930-31, 1934-36 from Mosher (1954); 1938-41, unpublished data from R.W. Wolf, U.S. Bureau of Commercial Fisheries; 1941-47 from Felin and Phillips (1948); 1947-48 from Mosher et al. (1949). California ports: 1949-55 from Felin et al. (1950 et seq.); 1955-57 from Felin et al. (1958). San Pedro: 1957-58 unpublished data from R.W. Wolf.

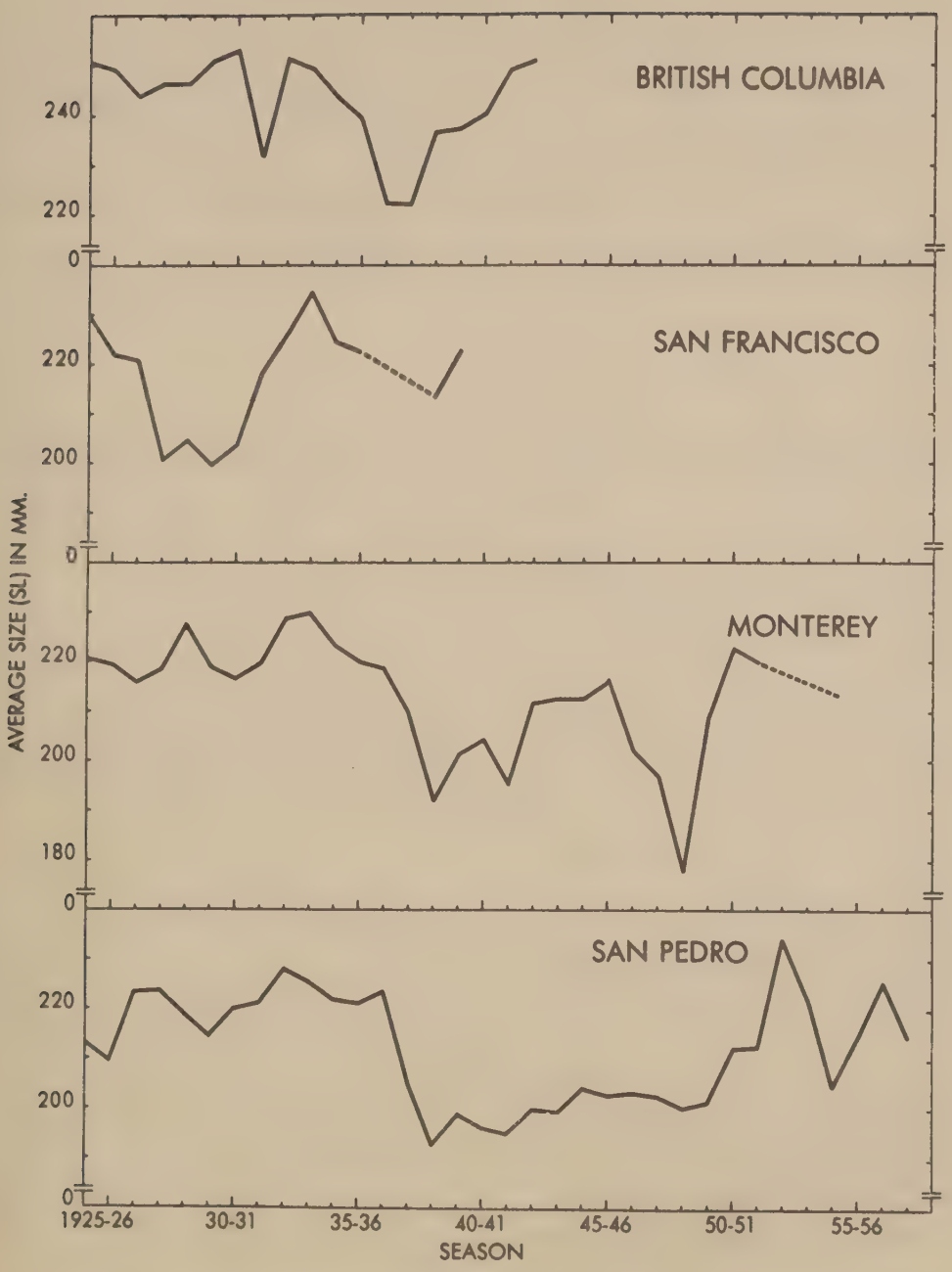

Fig. 17 Average size (standard length) of fish in the sardine catch at British Columbia, San Francisco, Monterey and San Pedro. Data are from Table VII.

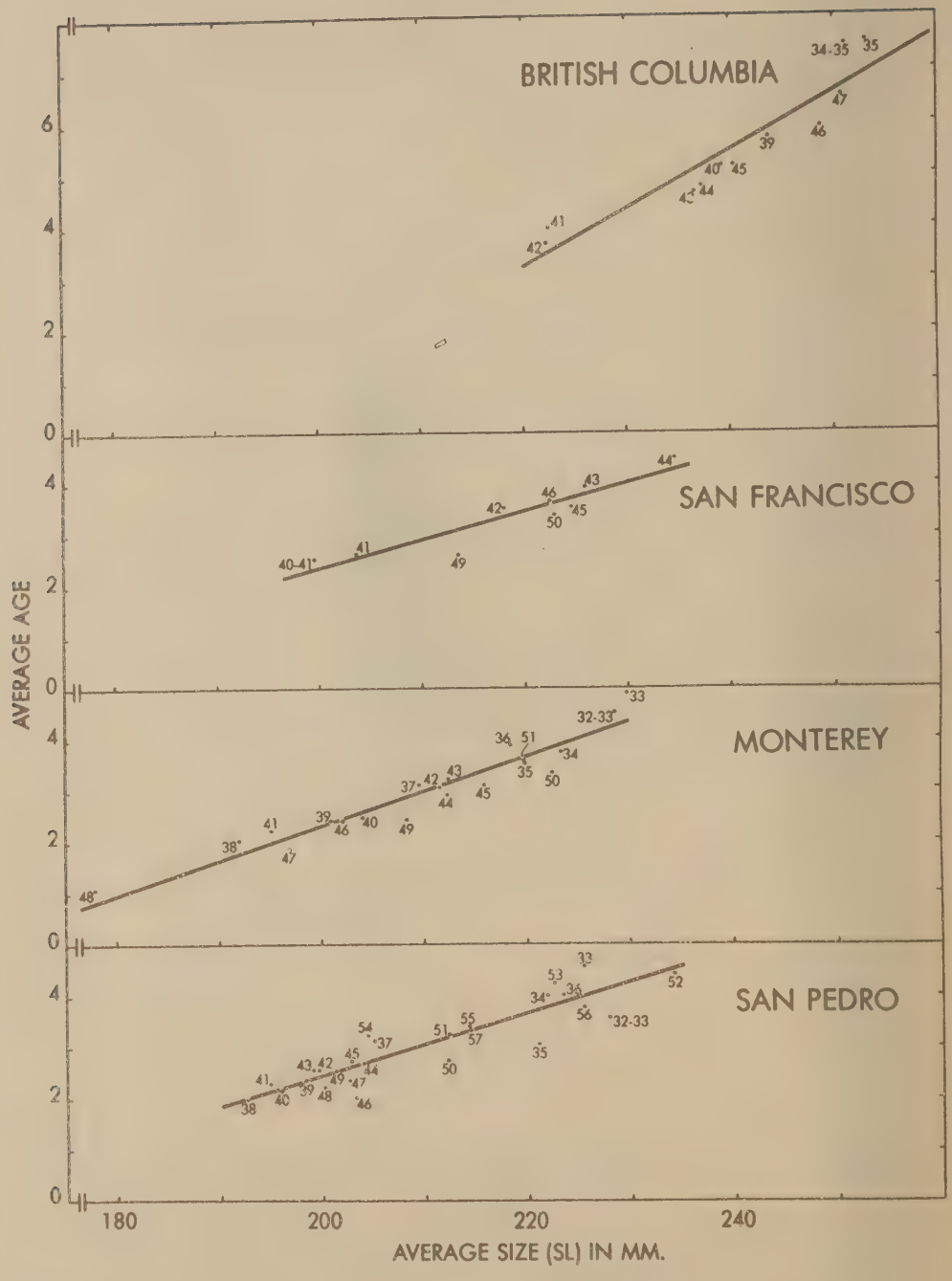

Fig. 18 Regression of average age on average size of fish in the sardine catch at British Columbia, San Francisco, Monterey and San Pedro. Data are from Tables III and VII.

Since age and length are closely related, it is not surprising to find that the average length curves closely approximate the average age curves (see Fig. 6). The general course of these average length curves and the variations about the general trends without doubt result from the same influence affecting the average age curves. The discussion need not be repeated here, except to state that a fraction (less than half) of the observed changes may be attributed to changes in fishing intensity, with the major proportion being attributed to variations in year class size and availability (see 3.1.1).

The degree to which average age and length are associated at the four ports is shown in the age-on-length regressions of Fig. 18. The regression equations (least squares fit) and correlation coefficients are :

Area	Regression	r
British Columbia	$Y = -21.337 + 0.1115X$	$+ 0.937$, $P < .01$
San Francisco	$Y = - 8.64 + 0.055X$	$+ 0.929$, $P < .01$
Monterey	$Y = -10.867 + 0.066X$	$+ 0.957$, $P < .01$
San Pedro	$Y = - 9.224 + 0.058X$	$+ 0.907$, $P < .01$

The association between average age and average length is obviously quite high in all areas. The regression for British Columbia is characterized by a high slope and intercept, relative to the other ports. The regressions for the three California ports are quite similar.

Since the length data in all cases extend over a longer period than do the age data, the regression equations may be used to estimate average ages in the earlier periods for which there are no age data. The results are given in Table VIII and will be of use in a subsequent section dealing with mortality rates.

3.2.2 Average length at end of first year of life

It is possible to estimate the size of an individual fish at earlier ages, given information on fish size and scale size at time of capture and scale size at the earlier ages. Fish length at the end of the first year of life has been estimated for the sardine, under the assumption of direct proportionality between fish growth and scale growth. Average length at the end of the first year of life ($\bar{l}_1$) has been determined by year class. Data are given in Table IX and Fig. 19. The $\bar{l}_1$ for a particular year class is based on all available individuals of that year class, regardless of the age at capture.

The means of year class $\bar{l}_1$ are 107.9 mm in British Columbia, 109.6 mm at San Francisco, 115.4 mm at Monterey, and 120.1 mm at San Pedro. This apparent cline in mean $\bar{l}_1$ is associated, in part at least, with the fact that the data do not include the same time periods at all ports.

Table VIII

ESTIMATES OF AVERAGE AGE OF SARDINES IN THE CATCH, BASED ON THE REGRESSIONS OF AVERAGE AGE ON AVERAGE LENGTH

Season	San Pedro	Monterey	San Francisco	British Columbia
1924-25	3.27	3.69	-	-
1925-26	3.02	3.60	-	-
1926-27	3.82	3.38	-	-
1927-28	3.84	3.56	-	-
1928-29	3.56	4.15	-	-
1929-30	3.31	3.58	-	6.63
1930-31	3.63	3.42	-	6.45
1931-32	3.69	3.63	-	5.87
1932-33	-	-	-	6.17
1933-34	-	-	-	6.17
1934-35	-	-	-	-
1935-36	-	-	3.98	-
1936-37	-	-	3.56	4.55
1937-38	-	-	3.50	6.67
1938-39	-	-	2.39	6.46
1939-40	-	-	2.61	-

Omitting those year classes represented by fewer than ten individuals, the $\overline{l}_1$ for the 1933 through 1943 classes vary around a level of slightly less than 105 mm in all four areas. The variations between year classes tend to be of the same magnitude and direction in all areas.

The $\overline{l}_1$ for the 1944 through 1957 classes at San Pedro tend to vary as much, or perhaps slightly more, than do those of the earlier year classes. However, the level about which they vary is considerably higher, slightly less than 135 mm. In addition, this level may not be horizontal, but rather tends to increase for the more recent year classes.

Table IX

AVERAGE CALCULATED SARDINE LENGTH AT END OF FIRST YEAR OF LIFE ($\overline{T}_1$) BY YEAR CLASSES AT THE SEVERAL PORTS [17/]

Year class	San Pedro		Monterey		San Francisco		British Columbia	
	$\overline{T}_1$	n	$\overline{T}_1$	n	$\overline{T}_1$	n	$\overline{T}_1$	n
1930	-	-	-	-	-	-	114.0	2
1931	-	-	-	-	-	-	112.0	2
1932	-	-	-	-	-	-	120.0	4
1933	-	-	-	-	102.0	1	111.7	15
1934	94.0	1	96.0	4	112.3	6	108.2	32
1935	99.4	13	98.2	20	94.4	21	103.6	88
1936	104.2	62	101.6	146	100.9	195	103.2	301
1937	104.5	245	107.2	498	109.2	716	115.3	501
1938	97.6	1755	101.4	2254	104.0	2376	106.3	539
1939	93.1	3612	95.5	5846	97.0	4161	94.2	1155
1940	108.7	2813	109.7	2347	109.4	1476	106.8	466
1941	102.3	2723	101.8	869	105.0	317	113.1	35
1942	101.6	1777	97.6	2345	99.6	565	95.8	109
1943	110.5	1136	107.1	854	108.8	204	110.2	63
1944	125.6	594	113.4	222	114.6	41	124.0	3
1945	139.1	875	114.2	552	126.8	51	88.0	1
1946	116.7	1068	109.2	753	116.2	111	-	-
1947	130.9	966	107.6	1353	108.0	233	-	-
1948	138.5	1441	142.5	190	146.1	14	-	-
1949	133.4	201	126.9	15	-	-	-	-
1950	128.9	207	128.3	14	-	-	-	-
1951	121.8	596	-	-	-	-	-	-
1952	128.8	1113	157.0	1	-	-	-	-
1953	143.0	442	-	-	-	-	-	-
1954	137.4	347	131.7	4	-	-	-	-
1955	131.3	381	118.5	128	-	-	-	-
1956	136.2	636	128.8	499	-	-	-	-
1957	155.1	104	147.7	84	-	-	-	-
Σ =	2882.6		2541.9		1754.3		1726.4	
N =	24		22		16		16	
$\overline{X}$ =	120.1		115.4		109.6		107.9	

17/ Data are from the files of the U.S. Bureau of Commercial Fisheries, made available through the courtesy of R.W. Wolf.

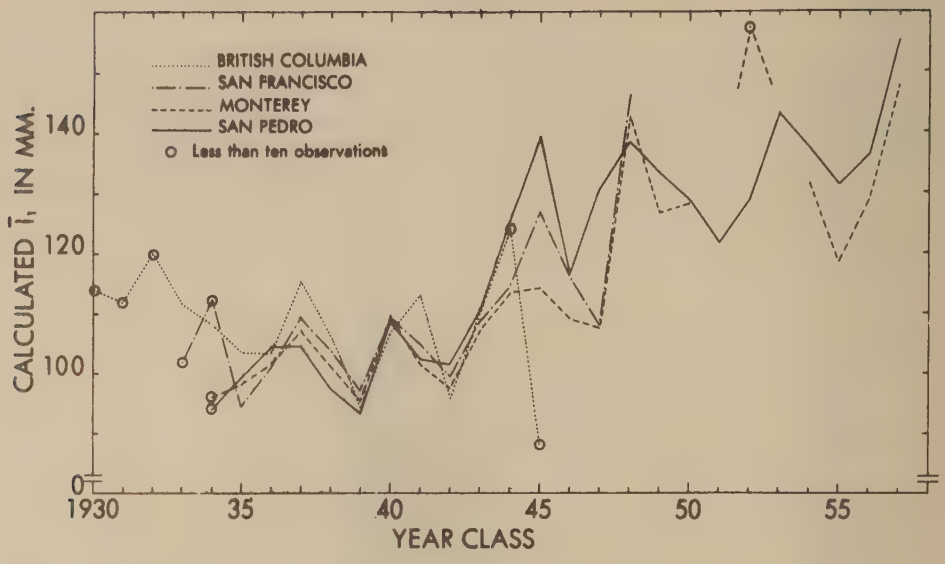

Fig. 19 Average calculated length at the end of the first year of life ($\bar{l}_1$) of sardine year classes at British Columbia, San Francisco, Monterey and San Pedro. Data are from Table IX.

The $\bar{l}_1$ for the 1944 through 1947 classes at Monterey tend to vary about a level intermediate to the early (low) and late (high) levels already described at San Pedro. For the 1948 and subsequent year classes at Monterey, the $\bar{l}_1$ level corresponds to that for San Pedro.

The $\bar{l}_1$ at San Francisco approximate the intermediate level at Monterey for the 1944 through 1947 classes, although they are somewhat higher for the 1945 and 1946 classes. The $\bar{l}_1$ for the 1948 class, the last for which there are data at San Francisco, is at the late (high) level of San Pedro and Monterey.

There are no data for British Columbia for this later period.

The curve of year class $\bar{I}_1$ at San Pedro not only shows two levels about which the individual values vary, but creates the impression that the transition from one level to the other occurred abruptly following the 1943 class. The relative abruptness of the change may be examined by expressing the $\bar{I}_1$ of any particular year class as a percentage increase or decrease of the $\bar{I}_1$ of the previous year class. Data on these changes are shown in Fig. 20.

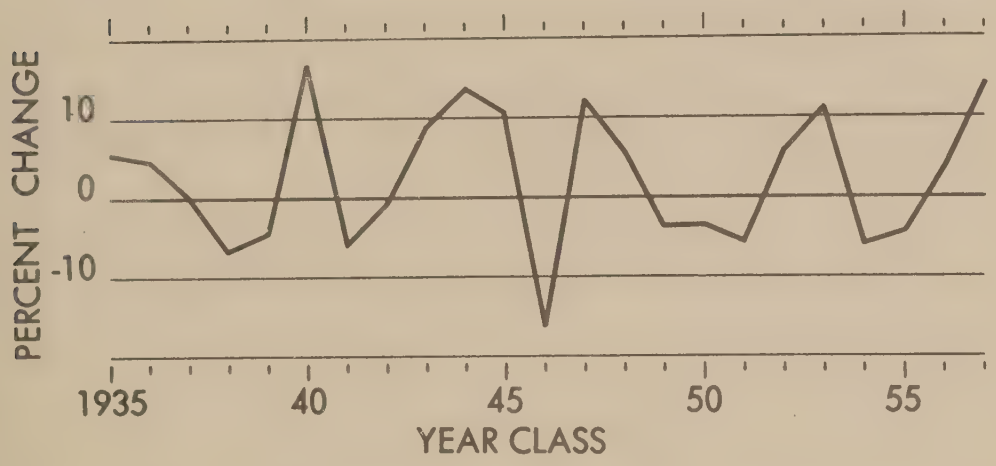

Fig. 20 **Change in sardine year class $\bar{I}_1$ at San Pedro, expressed as a percentage increase or decrease from the $\bar{I}_1$ of the previous year class. Data are from Table IX.**

While the 1944 class $\bar{I}_1$ does show a large change relative to the 1943 class $\bar{I}_1$, there are more striking changes exhibited by other year classes. The 1940 and 1946 classes, for example, show large changes relative to adjacent classes. The transition from the lower to the higher level was the result of substantial increases in $\bar{I}_1$ in three successive year classes, 1943, 1944 and 1945. However, the $\bar{I}_1$ for the 1943 class does not exceed the previous variation about the lower level, so the transition to the higher level may be attributed to the 1944 and 1945 classes.

In seeking an explanation for the observed change in $\bar{T}_1$, one obvious possibility is that $\bar{T}_1$ may be density dependent. Indeed, this possibility has already been suggested in effect by Phillips (1948). In order to examine this possibility, the $\bar{T}_1$ data for San Pedro were used, since they cover the longest period and are similar to the data for the other areas (with the exceptions already noted). The $\bar{T}_1$ data were compared with accumulated age estimates of year class size. (The derivation of these estimates is explained later). The comparisons were made with year class size estimates rather than total population size estimates since, if growth is related to competition, intra-year class rather than intra-specific competition seems likely to be most important for sardines in their first year of life. This judgment is made on the basis of :

(a) the tendency for fish to school by size (Radovich, 1952);

(b) differences in food habits between young and adult fish (Arthur, 1956 ; Radovich, 1952);

(c) differences in distribution between young and adult fish (young fish are initially restricted to the spawning grounds and expand, or at least change, their distributions from these areas during their first year of life, whereas adults inhabit a much larger area during a year).

In addition, year classes on the average are almost equal in size to the populations to which they are added (Clark and Marr, 1955), so that even if the young fish were competing with adults as well as with each other, the situation on the average would not be that of a relatively small group of young fish competing with a relatively large group of adults (as might be the case in a species having a large number of year classes in the population).

The $\bar{T}_1$ of the 1935 through 1955 classes at San Pedro are plotted against year class size estimates in Fig. 21. The regression equation (least squares fit) is :

$$Y = 130.86 - 5.72X \qquad r = -0.71, \; P < .01$$

A second degree curve may improve the fit, but only slightly so.

An obvious conclusion is that $\bar{T}_1$ is density dependent; that is, that on the average, sardine growth during the first year of life tends to be small when year class size is large, and to be large when year class size is small. An alternative interpretation is possible, however. If one considers the 1935 through 1943 classes, the correlation between $\bar{T}_1$ and year class size is not significant ($r = -0.59$, $P > .05$); neither is the correlation significant for the 1944 through 1955 classes ($r = -0.20$, $P > .05$). If $\bar{T}_1$ is not related to year class size, what could account for the high $\bar{T}_1$ level following the 1943 class? It could be accounted for by earlier spawning, which would allow more time for growth during the first year of life, or by an increased food supply, which would also allow greater growth. It is known that during the 1950 through 1956 period the peak spawning months off central Baja California were March - April, while the peak spawning months off southern California were April - June (Ahlstrom, 1954a, 1959; Marr, 1957, 1960, and in press). Thus, sardines produced off central Baja California would have had, on the average, about one to one-and-a-half more months in which to grow during their first year of life than would fish produced off southern California. How-

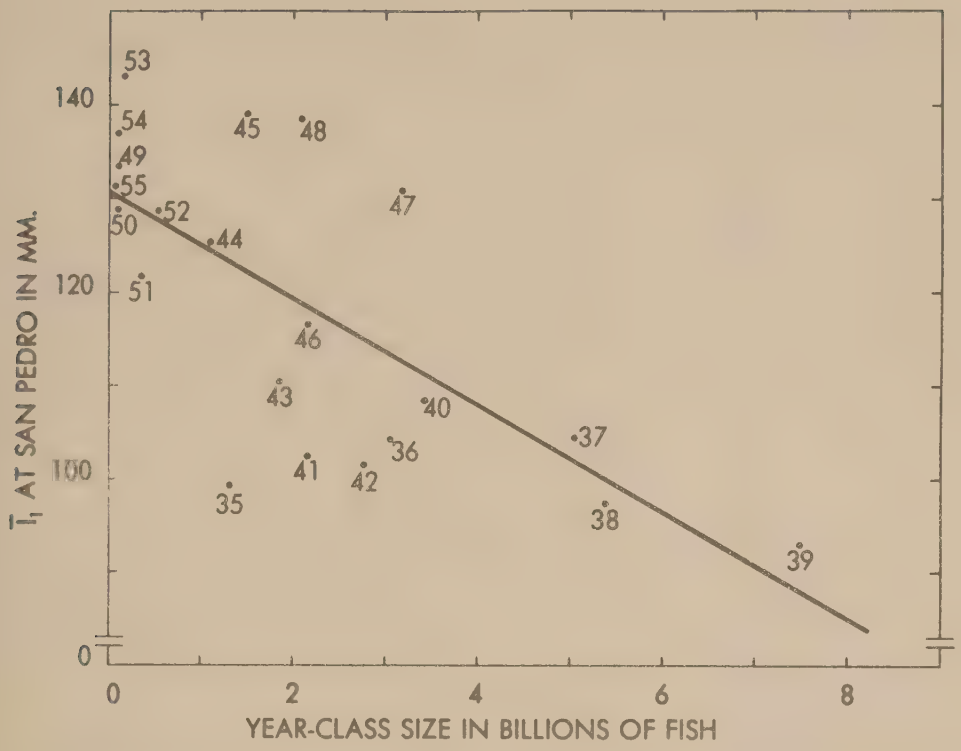

Fig. 21 **Regression of sardine year class $\bar{l}_1$ at San Pedro on accumulated age estimates of year class size. Data are from Tables IX and XIV.**

ever, it seems likely that the post-1943 increased $\bar{l}_1$ may be explained on the basis of a density independent increase in food supply associated with colder surface layers (Reid et al., 1958). **The evidence bearing on this and related problems is reviewed in 5.4.**

3.2.3 Growth (length-on-age) curves

Sardine growth data have been given in various forms by Phillips (1948), Felin (1954), and Clark and Marr (1955), among others. Data on average standard length by ages in the

four areas (as observed at time of capture, i.e. not back calculated from scales) are given in Table X and shown in Fig. 22. Since these data have already been considered in some detail, only the general features will be described here.

Table X

SARDINE AVERAGE STANDARD LENGTH AND WEIGHT, BY AGES AND AREA

Age (rings)	British Columbia		San Francisco		Monterey		San Pedro	
	SL[18] (mm)	Weight[19] (gm)	SL[18]	Weight	SL[18]	Weight[20]	SL[18]	Weight[20]
1	179	69	176	-	172	69	183	79
2	201	104	207	-	203	114	200	102
3	223	143	221	-	218	145	208	115
4	236	177	227	-	225	160	214	124
5	242	196	232	-	232	172	220	135
6	246	211	240	-	240	189	226	148
7	249	222	247	-	247	202	234	165
8	253	232	248	-	249	204	245	185
9	255	240	249	-	251	209	252	202
10	257	243	-	-	252	-	253	-
11	260	245	-	-	253	-	254	-
12	261	247	-	-	256	-	255	-

18/ Length data from Felin and Phillips (1948), Eckles (1954) and Clark and Marr (1955).

19/ British Columbia weight data made available through the courtesy of Dr. J.L. Hart, Fisheries Research Board of Canada.

20/ Monterey and San Pedro weight data made available through the courtesy of J.S. MacGregor, U.S. Bureau of Commercial Fisheries.

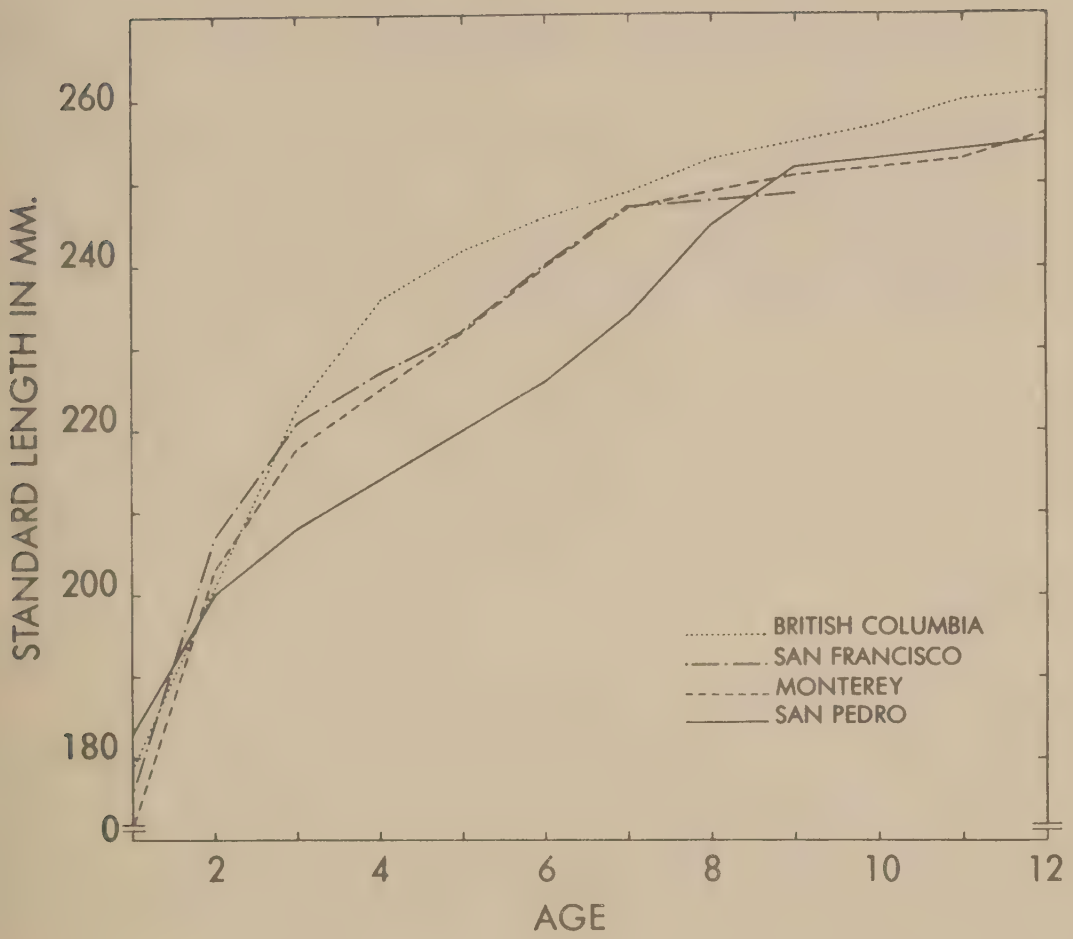

Fig. 22 Average size at successive ages of fish in the sardine catch at British Columbia, San Francisco, Monterey and San Pedro. Data are from Table X.

The length-on-age curve for British Columbia is the most regular. The points for ages one and two are intermediate to the data for other ports. By age three, British Columbia fish are longer on the average than fish from the California ports. This relationship is maintained over all successive ages.

The curves for San Francisco and Monterey greatly resemble each other. They also greatly resemble the curve for British Columbia through age three. It is apparent that the curves for San Francisco and Monterey are not regular. It is not apparent, however, from this form of plot (Fig. 22) whether the aberrant points are those for ages four through six or ages five through seven. A choice may be more readily made on the basis of the plot of average length increment-on-age (Fig. 23). The increments in ages six, seven and possibly five, are greater than would be expected on the basis of increments at younger and older ages.

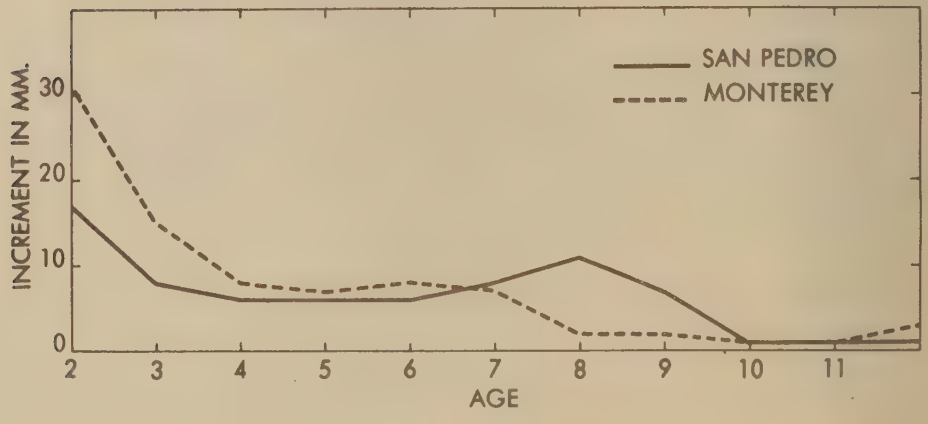

Fig. 23 Average growth increments at successive ages of fish in the sardine catch at Monterey and San Pedro. Data are from Table X.

The length-on-age curve for San Pedro exceeds the other three at age one. By age two, San Pedro fish are smaller on the average than those from the other ports. This relationship obtains until age nine, when the average slightly exceeds average size at Monterey and San Francisco. The curves for San Pedro and Monterey are similar for ages nine through 12. From ages two through six, the San Pedro curve is much flatter than the other curves. There is an increase in annual increment at ages seven through nine, and the level of the curve after age six is higher than would be expected on the basis of the points for the first six years. As may be seen in Fig. 23, the points for ages seven through nine, and possibly five and six, are aberrant.

Thus, the curve for British Columbia is regular, while those for the other three ports exhibit irregularities. The irregularities at San Francisco and Monterey occur one or two ages earlier than the irregularities at San Pedro. A possible explanation of these features of the average length-on-age curves is that they are based on at least two groups of fish that have experienced different growth histories. One group may be characterized by the curve observed in British Columbia, while the other group may be characterized by the early portion of the curve observed at San Pedro. The curves for Monterey and San Francisco may represent varying mixtures of fish of these two groups. The irregularities noted in the curves for the three California ports apparently represent a decrease in the number of the San Pedro type and a consequent shift in the curve toward the British Columbia type. If this explanation is correct, the fish represented in the early part of the San Pedro curve are either relatively short-lived or otherwise unavailable to the fishery at older ages.

Phillips (1948), Felin (1954), and Clark and Marr (1955) have already commented on these possibilities.

It has been proposed many times (e.g. Clark and Janssen, 1945) that the south to north increase in average length for a given age can be accounted for by differential migration, i.e. the largest individuals of a particular age group tend to make the longest migrations. If this were so, that is, if for any particular age at San Pedro only those fish in some segment of the upper tail of the length frequency distribution migrated to British Columbia, the length-on-age curve at British Columbia should approximate that for San Pedro plus some constant percentage increment. This is obviously not the case. As described in the preceding paragraphs, while the British Columbia curve appears to be based on a reasonably homogeneous group of fish, the curves for the California ports most certainly are not. Thus, while differential migration by size undoubtedly occurs, it cannot account for the observed differences in average length-on-age curves for the four areas.

Additional evidence in support of the existence of groups of fish with different growth histories has been given by Felin (1954), who utilized data on calculated lengths at earlier ages. Other direct evidence is available from the data on the length frequency distributions in the areas, by seasons and year classes (Felin and Phillips, 1948; Mosher et al., 1949; Felin et al., 1949; et seq.), which often exhibit bimodality and which, in addition, were shown by Ronquillo (MS) to differ not only between ports in mean value, but also in variance about the means.

3.2.4 Growth by seasons

In addition to the various aspects of length and growth that have already been considered,

it is of interest to consider differences in growth between seasons. Owing to the obvious facts that (a) fish of different ages grow different amounts, and (b) fish of different ages are present in varying proportions from season to season, it is impractical to derive a measure of the absolute growth experienced by all the fish in the population during a given time period. (The fact that initial size, at a given age, might be expected to effect growth expectation during a season has not been taken into account.)

In order to overcome this difficulty, it was necessary to determine the average annual and seasonal growth increment for each age. For a given season the observed increments were expressed as a percentage of the average increments. The unweighted average of these percentages was taken as a relative measure of annual growth for each season in each area. (Only the data for ages one through five were used in estimating relative annual growth, to avoid giving undue weight to older ages represented by few individuals). The data are given in Tables XI and XII.

As an example, certain data for San Pedro are shown in Fig. 24. These include (a) the average annual increments for the 1941-42 through 1953-54 seasons, (b) the annual increments for the 1949-50 season, and (c) the annual increments of the 1949-50 season expressed as percentages of the average annual increments.

Relative growth measures, by season and based on ages one through five, are given in Table XII and Fig. 25. Although there are some points of difference, the curves for the four areas a remarkably similar. The seasons of below-average and above-average growth in British Columbia tend to occur one year later than they do in California. In California the direction of change is similar between ports, although the magnitude of the change may not be identical. The 1946-47 season, for example, tended to be low at all three ports, but was below average only at San Pedro. Considering direction of change rather than magnitude, then, the "lows" in California occurred in 1941-42, 1945-46 or 1946-47, and 1950-51. The "highs" occurred in 1944-45, 1947-48 or 1948-49 and 1952-53.

The close agreement between areas of this relative measure of annual growth indicates that either the conditions affecting growth tend to be the same over relatively wide areas, or that the fish tend to be all in the same area during their period of growth. Information in the previous section (growth curves), what is known of sardine biology in general, and what is known of the northeast Pacific, all argue in favor of the former alternative.

Although Phillips (1948) has suggested a density dependent relationship between growth and population size, these data do not confirm his suggestion. With the longer series of data now available, it is apparent that annual growth is not a function of population size. This is shown, for example, by a comparison of the growth data for San Pedro in Table XII with the population size estimates for either San Pedro or the entire area in Table XV. It seems likely that Phillips was led to his suggestion because his observations were based, in part at least, on a period of above-average growth. This lack of density dependence is interesting in connection with (and perhaps in contrast to) the work of MacGregor (1959), who found an inverse relationship between condition factor and population area.

Table XI

SARDINE AVERAGE ANNUAL GROWTH INCREMENT BY AGES FOR EACH PORT, ANNUAL GROWTH INCREMENTS AND ANNUAL INCREMENTS EXPRESSED AS A PERCENTAGE OF THE AVERAGE INCREMENT [21/]

Age (rings) when caught	Ave. Inc.	1941-42 Inc.	%	42-43 Inc.	%	43-44 Inc.	%	44-45 Inc.	%	45-46 Inc.	%	46-47 Inc.	%	47-48 Inc.	%	48-49 Inc.	%	49-50 Inc.	%	50-51 Inc.	%	51-52 Inc.	%	52-53 Inc.	%	53-54 Inc.	%
British Columbia																											
1	70.80	70	99	72	102	55	78	81	114	76	107	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	33.80	38	112	30	89	-	-	32	95	30	89	-	-	39	115	-	-	-	-	-	-	-	-	-	-	-	-
3	17.50	15	86	23	131	14	80	19	108	19	108	15	86	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	11.16	8	72	12	107	8	72	9	80	18	160	9	80	14	124	-	-	-	-	-	-	-	-	-	-	-	-
5	6.00	6	100	3	50	6	100	8	133	7	117	5	83	7	117	-	-	-	-	-	-	-	-	-	-	-	-
6	4.57	4	87	4	87	5	109	5	109	6	131	3	152	5	109	-	-	-	-	-	-	-	-	-	-	-	-
7	3.86	2	52	5	130	5	130	4	104	4	104	4	104	4	104	-	-	-	-	-	-	-	-	-	-	-	-
8	3.29	3	91	3	91	3	91	3	91	2	61	4	122	5	152	-	-	-	-	-	-	-	-	-	-	-	-
9	2.67	2	75	4	149	2	75	2	75	3	112	-	-	3	112	-	-	-	-	-	-	-	-	-	-	-	-
10	6.00	-	-	-	-	-	-	-	-	-	-	-	-	6	100	-	-	-	-	-	-	-	-	-	-	-	-
11	1.66	1	60	2	120	2	120	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
San Francisco																											
1	63.43	53	84	74	117	73	115	71	112	69	109	57	90	-	-	-	-	47	74	-	-	-	-	-	-	-	-
2	28.45	26	91	26	91	32	112	38	133	29	102	33	116	-	-	-	-	35	123	15	53	-	-	-	-	-	-
3	14.00	10	71	13	93	15	107	19	136	15	107	18	128	-	-	-	-	13	93	9	64	-	-	-	-	-	-
4	9.13	8	88	7	77	10	110	10	110	10	110	12	132	-	-	-	-	8	88	8	88	-	-	-	-	-	-
5	5.88	5	85	4	68	7	119	7	119	6	102	5	85	-	-	-	-	8	136	5	85	-	-	-	-	-	-
6	5.42	8	147	4	74	6	111	5	92	6	111	5	92	-	-	-	-	-	-	4	74	-	-	-	-	-	-
7	4.20	6	142	4	95	4	95	4	95	4	95	3	71	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	4.83	4	83	4	83	12	248	3	62	3	62	3	62	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	3.50	-	-	-	-	-	-	-	-	4	114	3	86	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Monterey																											
1	64.90	57	88	66	102	68	105	66	102	64	99	67	103	78	120	74	114	51	79	-	-	58	89	-	-	-	-
2	28.73	25	87	29	101	28	97	38	132	29	101	30	104	34	118	31	108	34	118	16	56	22	77	-	-	-	-
3	14.64	11	75	14	96	15	102	19	130	15	102	14	96	22	150	21	143	11	75	9	61	10	68	-	-	-	-
4	8.82	8	91	8	91	10	113	10	113	10	113	9	102	10	113	10	113	8	91	7	79	7	79	-	-	-	-
5	6.45	7	109	5	78	7	109	7	109	6	93	7	109	8	124	7	109	7	109	4	62	6	93	-	-	-	-
6	5.22	6	115	5	96	5	96	5	96	5	96	5	96	-	-	-	-	6	115	4	77	6	115	-	-	-	-
7	3.56	4	112	5	140	2	56	3	84	2	56	4	112	-	-	-	-	4	112	3	84	5	140	-	-	-	-
8	4.57	-	-	-	-	6	131	4	88	4	88	4	88	4	88	-	-	6	131	4	88	-	-	-	-	-	-
9	3.50	-	-	-	-	4	114	3	86	-	-	-	-	-	-	-	-	-	-	-	--	-	-	-	-	-	-
10	2.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	100	-	-	-	-	-	-
San Pedro																											
1	60.73	58	96	66	109	72	119	73	120	68	112	52	86	60	99	64	105	49	81	-	-	62	102	-	-	44	72
2	26.00	25	96	26	100	25	96	36	138	30	115	24	92	23	88	33	127	26	100	17	65	19	73	24	92	30	115
3	13.62	10	73	16	117	16	117	16	117	15	110	14	103	15	110	14	103	10	73	10	73	10	73	17	125	14	103
4	8.85	7	79	9	102	11	124	11	124	9	102	8	90	10	113	8	90	6	68	7	79	8	90	12	136	9	102
5	7.08	5	71	7	99	8	113	7	99	7	99	6	85	7	99	8	113	5	71	5	71	10	141	9	127	8	113
6	5.54	11	199	5	90	5	90	6	108	5	90	6	108	7	126	6	108	2	36	3	54	3	54	7	126	6	108
7	5.00	6	120	4	80	5	100	7	140	4	80	4	80	5	100	-	-	4	80	-	-	3	60	6	120	7	140
8	4.80	-	-	-	-	-	-	4	83	4	83	2	42	8	167	-	-	-	-	-	-	-	-	-	-	6	125

21/ Data from the files of the U.S. Bureau of Commercial Fisheries made available through the courtesy of R.S. Wolf.

Table XII

RELATIVE ANNUAL SARDINE GROWTH, BASED ON AGES ONE THROUGH FIVE[22/]

Season	British Columbia	San Francisco	Monterey	San Pedro
1941-42	92	84	90	83
1942-43	93	89	94	105
1943-44	82	113	105	114
1944-45	106	125	117	120
1945-46	116	106	102	108
1946-47	83	110	103	91
1947-48	119	-	125	102
1948-49	-	-	117	108
1949-50	-	103	94	79
1950-51	-	72	64	72
1951-52	-	-	81	96
1952-53	-	-	-	120
1953-54	-	-	-	101

22/ See 3.2.4 for explanation.

3.3 Weight data

Relatively few data on weight, in contrast to data on length, have been published or are, indeed, available. Those considered here include :

(a) weight-length relationship, and
(b) condition factor.

3.3.1 Weight-length relationship

Weight-length data for sardines taken in British Columbia, Monterey and San Pedro are given in Table X and shown in Fig. 26. The equations of the fitted lines, of the form $W = kL^x$, are :

British Columbia	$W = 0.000007303\ L^{3.42137}$
Monterey	$W = 0.00005509\ L^{2.94682}$
San Pedro	$W = 0.00006131\ L^{2.95412}$

For a given length, sardines taken at Monterey are, on the average, heavier than those taken at San Pedro. For smaller lengths the weight of sardines in British Columbia approximates those taken at San Pedro. At larger lengths, British Columbia sardines are heavier than those taken at the California ports.

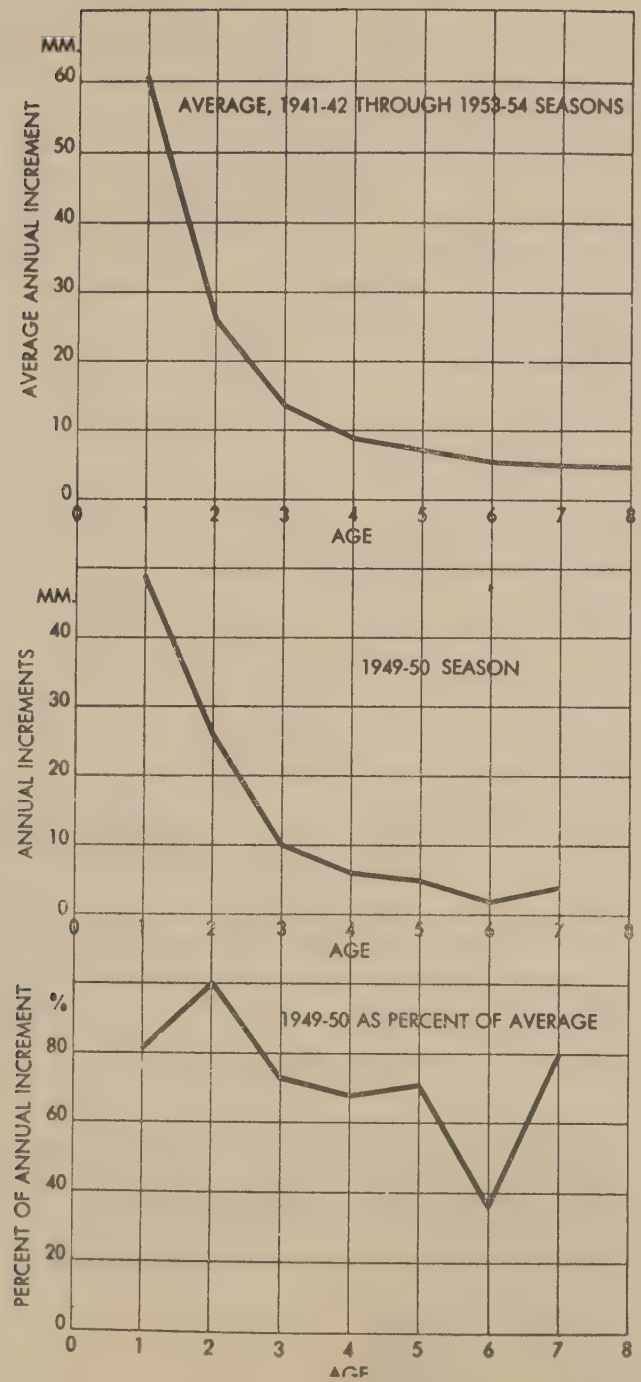

Fig. 24 **Average growth increments at successive ages of fish in sardine catch at San Pedro for the 1941-42 through 1953-54 seasons; annual increments for the 1949-50 season; and 1949-50 increments expressed as a percentage of the average. Data are from Table XI.**

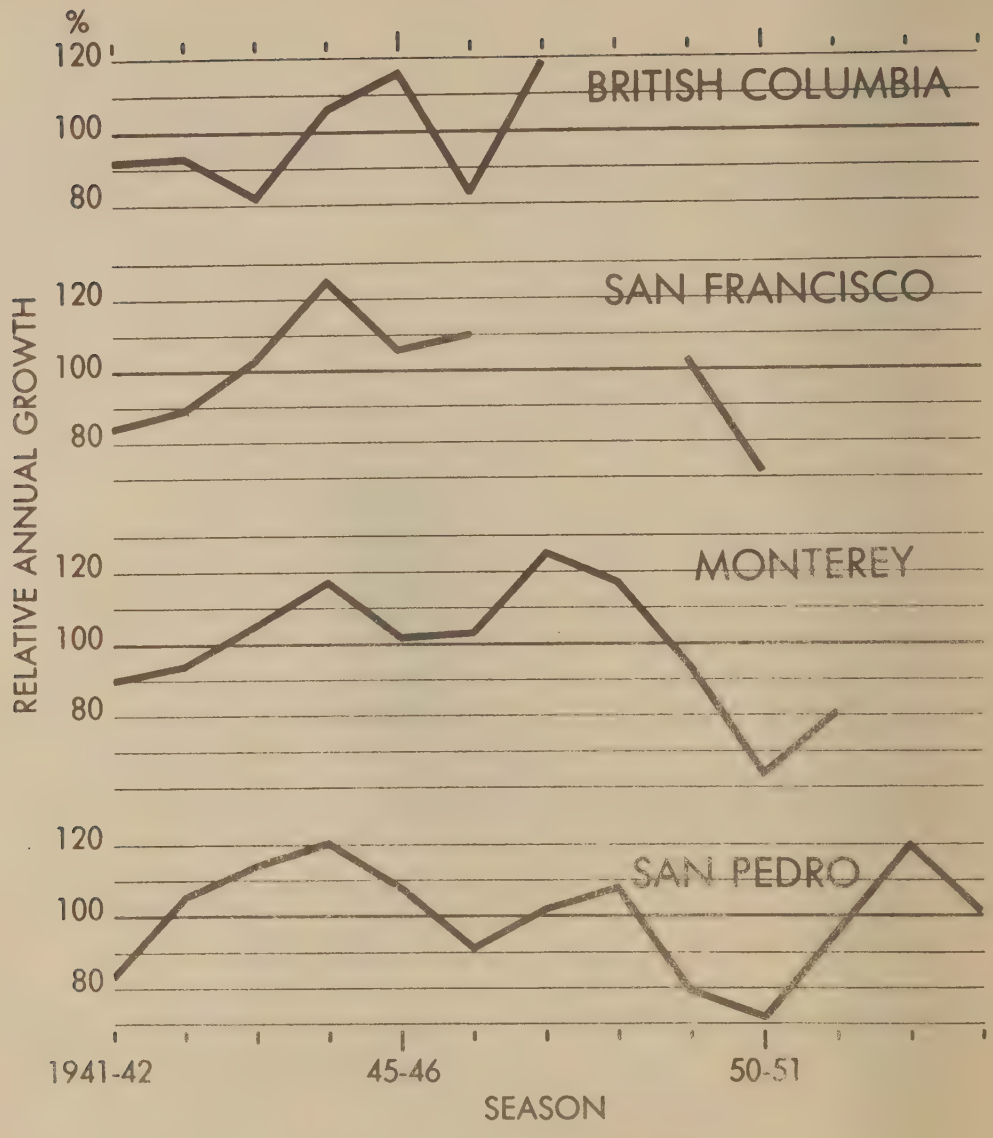

Fig. 25 Relative annual growth, based on ages one through five, of fish in the sardine catch at British Columbia, San Francisco, Monterey and San Pedro. Data are from Table XII. See text (3. 2. 4) for explanation.

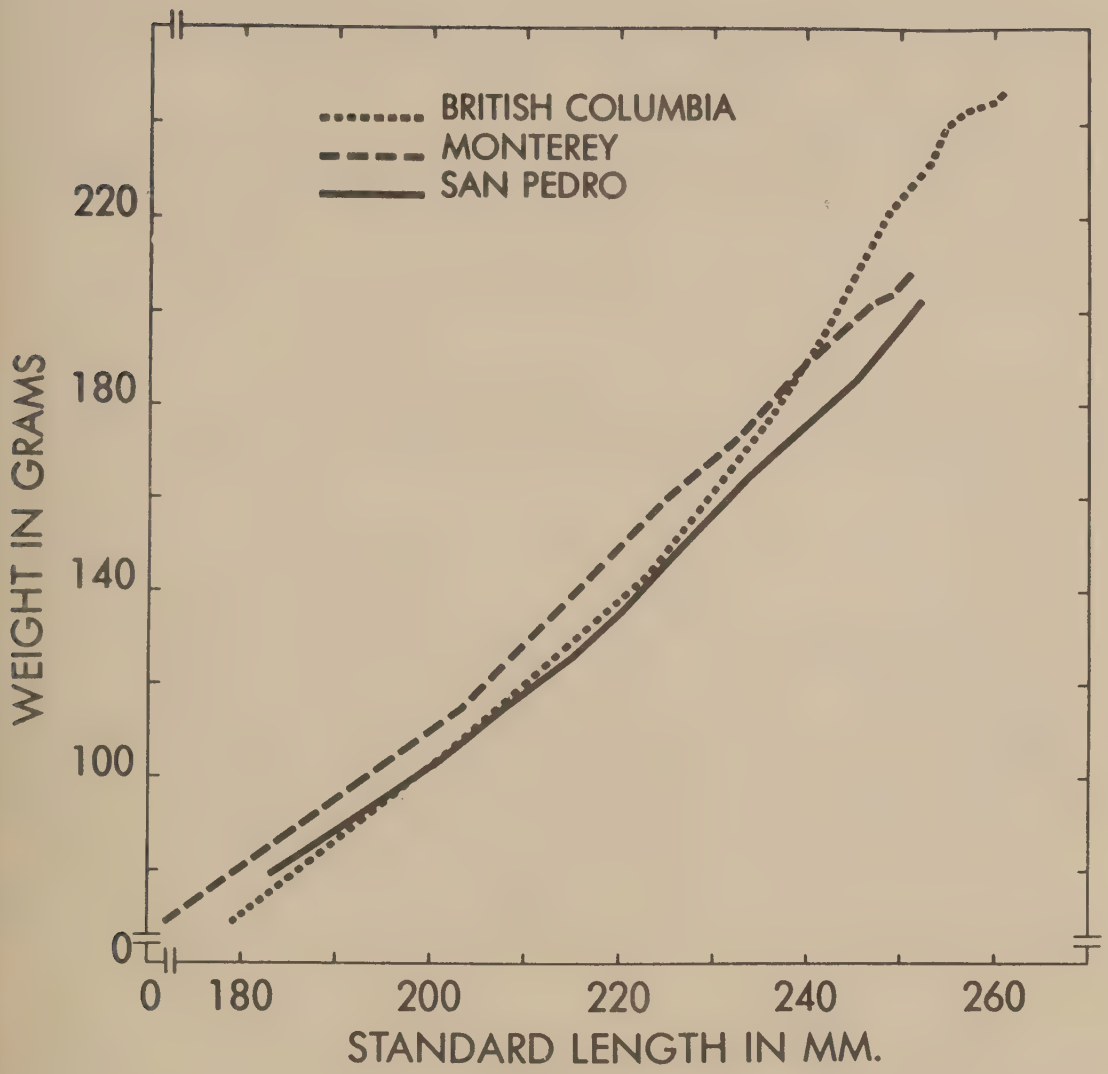

Fig. 26 Weight-length curves for fish in the sardine catch at British Columbia, Monterey and San Pedro. Data are from Table X.

The data for the California ports conform reasonably well to the "cube law", whereas the British Columbia data do not. The San Pedro data also compare reasonably well with data for an earlier period presented by Clark (1928, 1934).

3.3.2 Condition factor

MacGregor (1959) has given data on the condition factor of sardines taken at San Pedro for the 1941-42 through 1956-57 seasons (excluding the 1943-44 season, for which no data were available). He has generously made available the data for the 1957-58 and 1958-59 seasons, which are shown in Fig. 27.

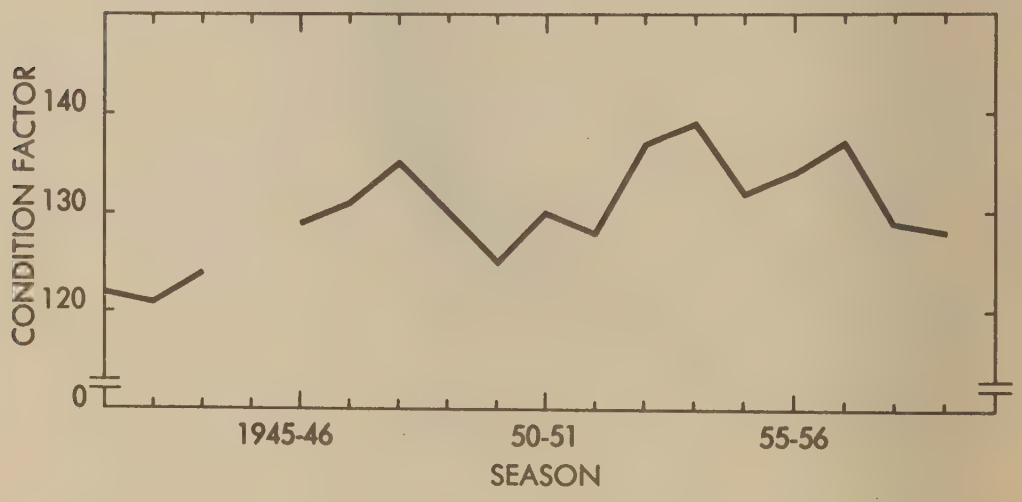

Fig. 27 Condition factor of fish in the sardine catch at San Pedro. Data largely from MacGregor (1959).

MacGregor found a significant correlation between condition factor and population size (as estimated by the catch) for the original series of data. The addition of two more seasons reduces the magnitude of the correlation coefficient, but the association is still greater than would be expected by chance. He attributed this relationship to competition for food. An interesting implication of this relationship is that intra-specific competition is more important than inter-specific competition among adults.

3.4 Availability

Evidence bearing on availability, and especially on changes in availability, has been brought together by Clark and Marr (1955). A summary will be useful here.

Pre-World War II tagging experiments carried out by the fishery agencies of the Pacific coast states of the United States and the Fisheries Research Board of Canada give some direct information. Some 140,000 tagged fish were released off the Pacific Northwest, central California, southern California and Baja California. Recovery facilities were available in all areas except Baja California. Fish tagged in the three northern areas were recovered in all. However, of the fish tagged of Baja California, about 75 per cent were recovered in southern California, about 25 per cent in central California, and only one was recovered in the Pacific Northwest.

Another line of evidence is afforded by variations in the catch. According to Clark and Marr (1955) : "Two outstanding examples of changes in availability can be cited for the California fishery. Between the 1945-46 and the 1946-47 seasons, there was a much greater than expected decline in all year classes in the fishery. Between the 1948-49 and the 1949-50 seasons, on the other hand, the decline was much less than expected. In fact, some year classes showed an increase. Since there must have been some natural mortality between these two seasons this increase in numbers on the fishing grounds can be explained only by increased availability in 1949-50. This anomaly of increased availability resulted from an influx of fish, perhaps from Baja California". Additional examples are available.

A third line of evidence derives from catch, effort and age data. Widrig (1954) gave maximal availability estimates for the 1941-42 through 1950-51 seasons. According to these estimates, availability has changed by a factor of four over periods as short as three seasons.

3.5 Spawning areas

The location of sardine spawning areas has been given by Ahlstrom (1954a, 1959, 1960) and Marr (1957, 1960, and in press), among others. There are four spawning areas which have been briefly characterized (Marr, 1960) as "(a) the area off southern California from Pt. Conception to northern Baja California (spring spawning), (b) the area off central Baja California (spring spawning), (c) the inshore area from Sebastian Viscaino south along the coast of Baja California (fall spawning) and (d) the Gulf of California (late winter-early spring spawning)". The four areas are shown in Fig. 28. This characterization is of course idealized. For example, the area off southern California may extend northward in some years. In general, it might be expected that the exact location of spawning areas is determined by oceanographic features rather than by geographic reference points (see 5.4).

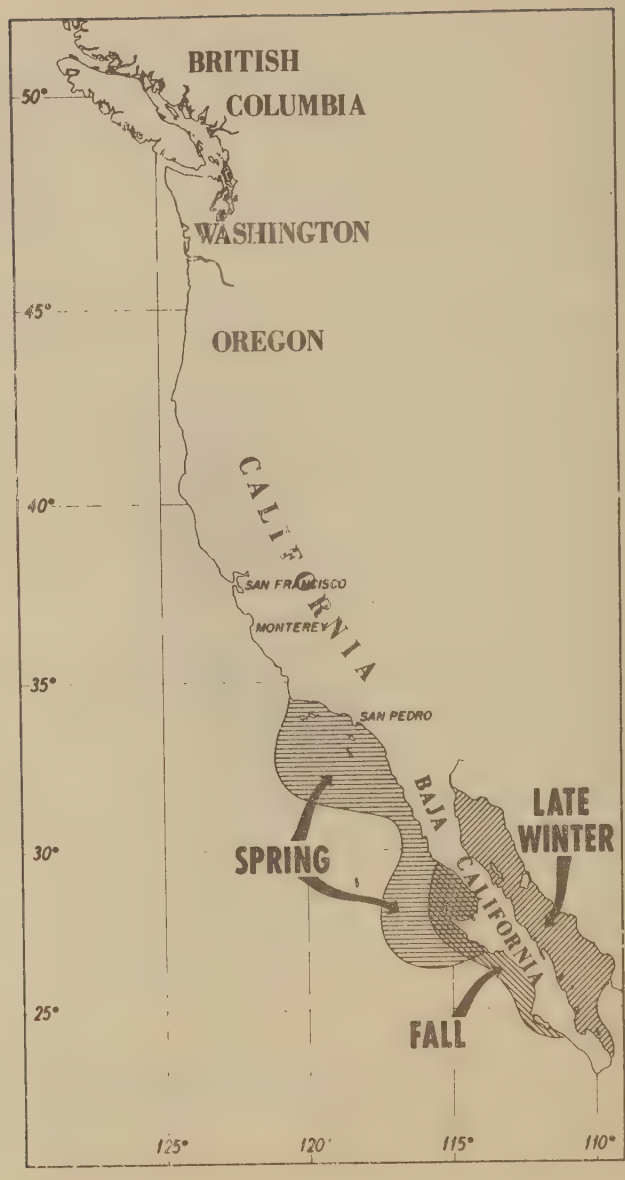

Fig. 28 Schematic representation of the location of sardine spawning areas. Modified from Marr (1960).

3.6 Mortality rates

Estimates of annual total, a, fishing, m, and natural, n, mortality rates from the 1932-33 through 1952-53 seasons, based on several types of data and analyses, were presented by Clark and Marr (1955). It is of interest to extend the series through more recent seasons. Estimates of all three rates may be derived from estimates of (a) total population size, and data on (b) total catch, and (c) age composition of the catch. The annual total mortality rate may be derived from the decline between two successive seasons of all year classes fully available in the first season[23/]. The annual fishing mortality rate may be derived by expressing the total catch (in numbers) as a percentage of the total population (in numbers). The annual natural mortality rate may then be derived by solving for n in a = m + n - mn.

Such estimates have been made for 1950 through 1957 and are given in Table XIII. Several sources of error and/or bias exist. Large changes in availability will affect the estimates of both a and n. For example, the tremendous decline in availability in the 1952-53 season results in ridiculously high estimates of total and natural mortality rates for 1952. Similarly, the increase in availability in the 1954-55 season results in negative values, equally ridiculous, for these mortality rates in 1954. The population estimates used are based upon knowledge of (a) the total number of eggs spawned per year, (b) fecundity, and (c) sex ratio. Data on the total number of eggs spawned are from Ahlstrom (1954, 1959, personnal communication). According to Taft (1960) the 95 per cent confidence limits of these estimates are about one-half and twice the estimate. If the population estimate exceeds the true value, the estimate of fishing mortality will be too low; if the population estimate is less than the true value, the estimate of fishing mortality will be too high. Fecundity estimates have been based on the assumption that three batches of eggs are spawned per year for a total of 100,000 eggs per female, on the average (Clark, 1934). Although the number of eggs per batch is well known, there is some reason to suspect that fewer than three batches are spawned per year (MacGregor, 1957). If this is so, estimates of population size will be too low and estimates of fishing mortality too high. If fecundity is variable, the estimates of population size and fishing mortality will be in error accordingly. The sex ratio closely approximates 1 : 1 (Phillips, 1948).

23/ This is a weighted estimate; i.e. in season B, the sum of all fish caught of year classes fully available in season A was divided by the sum of all fish caught of these same year classes in season A. Estimates so derived are more representative of the total annual mortality rate in the population than would be estimates based on the average total annual mortality rates by year classes, since there is apparently an age-specific increase in total annual mortality rate (or availability). Data suggesting this were given by Radovich (1952). Furthermore, year class catch curves tend to have somewhat dome-shaped right limbs, in the conventional plot of logarithm of numbers on age.

Table XIII

ESTIMATES OF SARDINE ANNUAL MORTALITY RATES AND SIZE OF SPAWNING POPULATION (in billions of fish)

Year	a	m	n	Population
1950	0.57	0.45	0.22	5.7
1951	0.71	0.08	0.68	12.2
1952	0.98	0.009	0.98	2.7
1953	0.51	0.002	0.51	8.8
1954	-	0.07	-	7.1
1955	0.47	0.13	0.39	4.0
1956	0.65	0.04	0.64	5.1
1957	0.66	0.08	0.63	2.0

It is apparent that the fishing mortality rate for the period 1951 through 1957 was at a low level, both absolutely and relative to earlier periods in the fishery. (Even if the true population size were one-half that estimated, fishing mortality rates would only be twice those given in Table XIII). Although less confidence may be placed in the estimates of natural mortality rates, these estimates tend to be considerably higher than those for earlier periods. If the estimates of natural mortality rates in Table XIII are of the right order, the sardine may be subject ordinarily to high natural mortality which tends to be "replaced" by fishing mortality during periods of an intense fishery.

3.7 Year class size estimates

Estimates of year class size may be made on an accumulated age basis (after Clark and Marr, 1955; these are analogous to the virtual population estimates of Fry, 1949). Accumulated age estimates of year class size are, simply, the total numbers caught of fish of a particular year class. Such estimates are obviously minimal. Since the estimate for any given year class is based on data collected over a period of years, possible bias arising from changes in natural mortality and availability will tend to be averaged out. However, as Dr. F. E. J. Fry, University of Toronto, has remarked (personal communication), trends in availability (and also in natural mortality and fishing effort), over periods that approximate year class persistence in the fishery, will introduce bias in these estimates.

It may also be remarked that, in general, this method of estimating year class size will, during periods of low fishing intensity, lead to estimates that are low relative to estimates made during periods of high fishing intensity. That is, on the average, year class strength will be under estimated during periods of low fishing intensity and over estimated during periods of high fishing intensity. Nevertheless, with respect to the sardine data, the accum-

ulated age estimate is, in my opinion, preferable to an estimate which takes variations in effort into account, for three reasons. First, data on a longer series of year classes are thus available. Second, an absolute (although minimal) rather than a relative estimate is obtained. Third, possible bias arising from events in a single season will tend to be averaged out.

In addition to those year classes represented at all ages in the fishery, and for which the data necessary for year class size estimates are therefore readily available, there are year classes for which there are data for fewer than all ages. For obvious reasons, this condition will obtain at the beginning and end of time series for which there are data on the age composition of the catch. A method of estimating the size of such year classes will be of obvious value in extending the series. The size of year classes incompletely represented in the catch may be estimated on the basis of the data given in Table VI and Fig. 16. That is, the contributions of these year classes by ages are assumed to have approximated the average contributions (based on all year classes for which there are complete data). These extrapolations will be in error to the extent that the year classes so estimated did not in fact contribute according to the average. It is quite likely that the estimates of earlier year classes exceed their true magnitude, since (a) fishing mortality was lower, (b) fish probably lived longer and, therefore, (c) more older fish were caught than would have been the case at the higher fishing mortality rates of later seasons.

Accumulated age estimates of year class size are given in Table XIV and shown in Figs. 29 and 30. The total estimates, based on the landings in all four areas (Fig. 29) include the 1934 through 1955 classes. The 1937, 1938 and especially the 1939 classes are outstandingly large. Accordingly, a decline in year class size from earlier to recent years is apparent. If, however, these three year classes are omitted, there is no apparent trend from the 1934 through 1948 classes. The 1949 through 1955 classes have been exceedingly small.

It is instructive to consider also year class size estimates by area. These are shown in Fig. 30. Estimates are available for the 1928 through 1943 classes in British Columbia, the 1934 through 1948 classes at San Francisco, the 1926 through 1950 classes at Monterey, and the 1926 through 1955 classes at San Pedro.

The curve of year class size in British Columbia declined from 1928 to 1931 and rose to a peak in 1939. By 1941 it had declined to about the 1931 level. 1942 and 1943 were at a low level, but somewhat higher than 1941.

To the extent that they overlap in time, the curve for San Francisco is similar to that for British Columbia. At San Francisco it rose from 1934 to a peak in 1939. It declined by 1941 to a level below that of 1934. It continued through 1948 at a low level, but 1942 and 1947 were somewhat above the general level of this period.

Table XIV

ACCUMULATED AGE ESTIMATES OF SARDINE YEAR CLASS SIZES, (in billions) [24/] [25/]

Year class	British Columbia	San Francisco	Monterey	San Pedro	Total
1926	-	-	3.001	4.464	-
1927	-	-	2.197	3.562	-
1928	0.339	-	1.512	2.360	-
1929	0.120	-	0.987	0.925	-
1930	0.047	-	0.531	0.396	-
1931	0.028	-	1.148	0.836	-
1932	0.076	-	1.453	1.597	-
1933	0.080	-	0.625	0.639	-
1934	0.095	0.232	0.449	0.200	0.976
1935	0.086	0.235	0.534	0.463	1.317
1936	0.199	0.599	1.263	0.997	3.058
1937	0.254	1.036	2.145	1.608	5.043
1938	0.271	1.422	1.846	1.849	5.388
1939	0.600	1.808	3.112	1.971	7.491
1940	0.205	0.504	1.198	1.519	3.426
1941	0.018	0.133	0.481	1.533	2.165
1942	0.059	0.241	1.311	1.172	2.784
1943	0.052	0.135	0.528	1.137	1.852
1944	-	0.016	0.119	0.963	1.097
1945	-	0.017	0.184	1.299	1.499
1946	-	0.040	0.393	1.737	2.170
1947	-	0.181	1.139	1.861	3.181
1948	-	0.019	0.110	1.950	2.079
1949	-	-	0.007	0.094	0.102
1950	-	-	0.014	0.091	0.104
1951	-	-	-	0.349	0.349
1952	-	-	-	0.543	0.543
1953	-	-	-	0.171	0.171
1954	-	-	-	0.096	0.096
1955	-	-	-	0.068	0.068

24/ All year classes were represented at all ages in the catch, except the following : the 1928 through 1936 classes and the 1939 through 1943 classes in British Columbia; the 1934 through 1938 classes and the 1945 through 1948 classes at San Francisco; the 1926 through 1929 classes and the 1947 through 1950 classes at Monterey; and the 1926 through 1930 classes and the 1950 through 1955 classes at San Pedro. Contributions of these year classes at the ages for which there are no data were estimated from the data given in Table VI and shown in Fig. 16.

25/ Data from sources indicated in Table I.

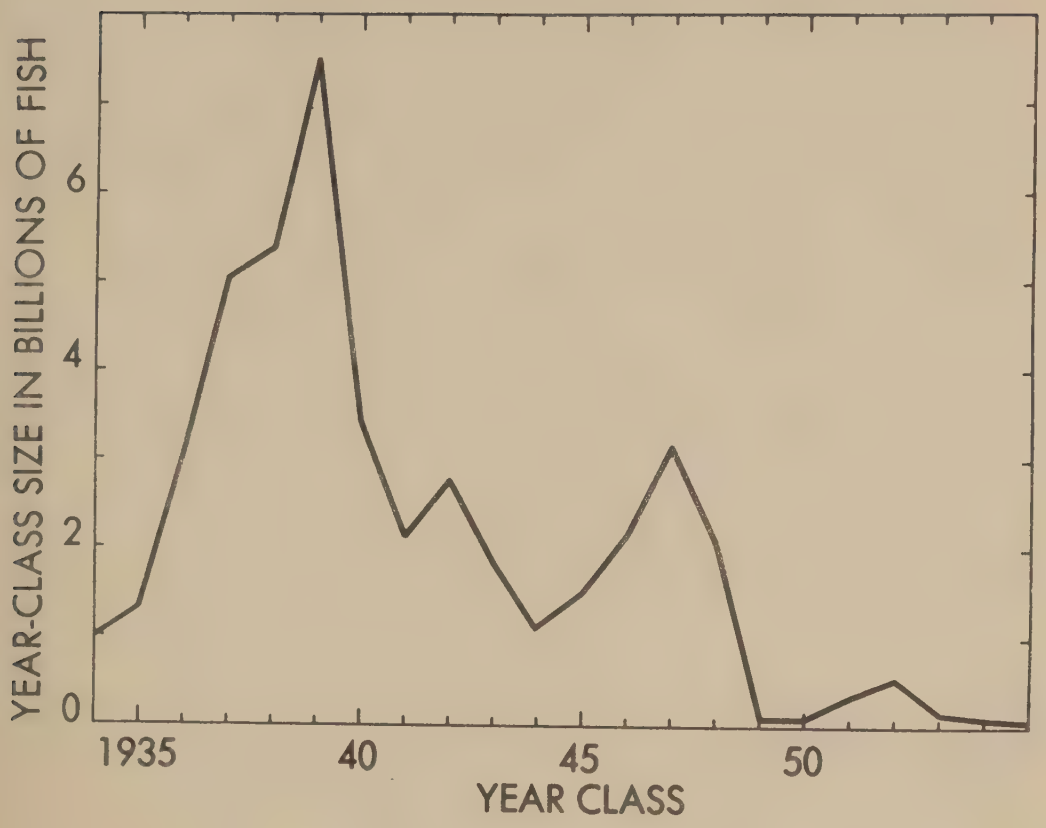

Fig 29 Accumulated age estimates of sardine year class size, all ports combined. Data are from Table XIV.

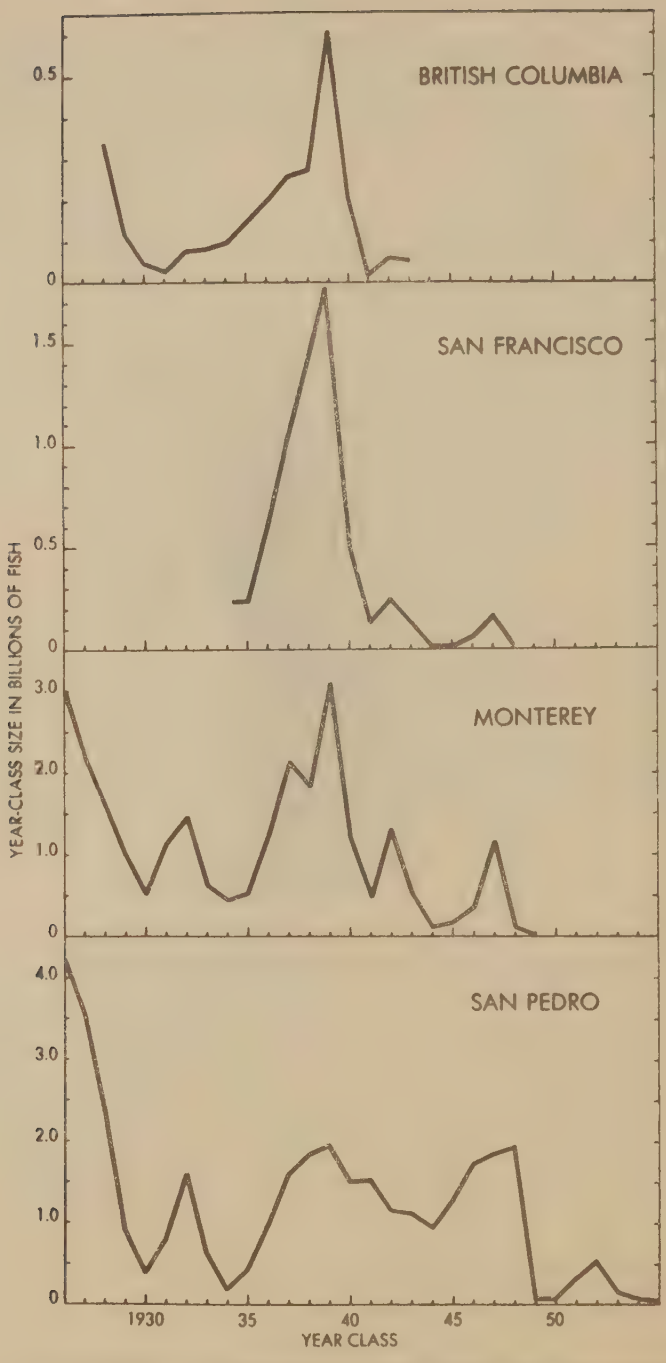

Fig. 30 Accumulated age estimates of sardine year class size at British Columbia, San Francisco, Monterey and San Pedro. Data are from Table XIV.

At Monterey, the curve of year class size fell from a high in 1926 to a low in 1930, rose to an intermediate peak in 1932, fell to 1934, rose to a peak in 1939, declined to 1941, rose to an intermediate peak in 1942, declined to 1944, rose to an intermediate peak in 1947, and declined to a low in 1948 through 1950. The two high points, 1926 and 1939, are at about the same level. For reasons given earlier, the points for the early year classes may be in excess of their true value, and the estimates involving seasons of low fishing intensity may be too low. The intermediate peaks, 1932, 1942 and 1947, are about even, and at a higher level relative to 1939 than was the case at San Francisco and British Columbia.

The curve for San Pedro declined from a high in 1926 to a low in 1930, rose to a peak in 1932, fell to 1934, rose to 1939, fell to an intermediate level in 1944, rose to a peak in 1948, fell to 1949, rose somewhat to 1952 and declined to 1955. The points for 1926 and 1927 are far in excess of any others and, for reasons given earlier, may be in excess of their true values, just as the estimates involving seasons of low fishing may be too low. The peaks for 1939 and 1948 are at about the same level, with the 1932 peak somewhat lower. The point for 1942 is relatively high, but not particularly so with reference to adjacent classes. The low for 1934 is much lower than the low for 1944. Thus, although the curve for San Pedro has basic similarities to the curves for the other areas, it is obvious that the relative magnitude of the year classes at San Pedro differs from their relative magnitudes at other ports.

Equally obvious, the absolute magnitude of year class size estimates varies between ports. In order to compare the relative magnitude of year classes at one area with the relative magnitude of the same year classes at another, it is convenient to weight the two sets of estimates to the same base. Estimates of the sizes of the 1928 through 1943 classes are available for both British Columbia and San Pedro. The British Columbia data were weighted to the total number of fish in the 1928 through 1943 classes at San Pedro. The original San Pedro data and the weighted British Columbia data are shown in Fig. 31. If the points for any given year class are at about the same level for both areas, it may be concluded that, relative to other year classes, that particular year class was equally well represented at both areas. In the case where the point for a given year class was higher at one area, then, relative to other year classes, that particular year class was more abundant at that area .... and so on.

Thus, the year classes in this series may be categorized as to whether they were relatively more abundant in British Columbia or at San Pedro. This may be more readily done if the differences between the two curves of Fig. 31 are plotted. This has been done in Fig. 32. The 1928 through 1930, 1933, 1935 and 1940 classes were of the same relative abundance at both ports. The 1934 and 1936 through 1938 classes were relatively more abundant in British Columbia, but slightly so. The 1939 class was relatively much more abundant in British Columbia. The 1931, 1932 and 1941 through 1943 classes were relatively more abundant at San Pedro than in British Columbia. The outstanding difference was exhibited by the 1939 class, followed by the 1941 and 1932 classes.

A similar comparison may be made over a longer period between Monterey and San Pedro, where estimates of the 1926 through 1950 classes are available. The original San Pedro data and the weighted (to the total number of fish in the 1926 through 1950 classes at San Pedro) Monterey data are shown in Fig. 33. The differences between the two curves are shown

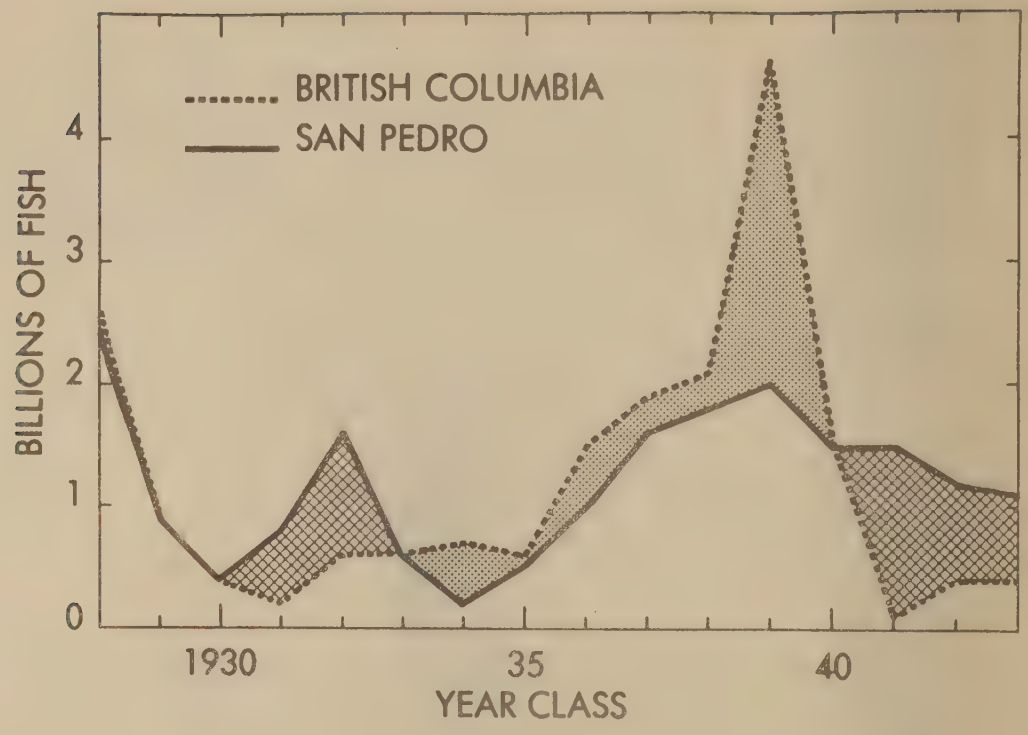

Fig. 31 Accumulated age estimates of sardine year class size at British Columbia and San Pedro. British Columbia estimates are weighted to San Pedro totals. Stippled areas indicate predominantly northern year classes; hatched areas indicate southern year classes. Based on data from Table XIV. See text (3.7) for explanation.

Fig. 32 Differences between the curves of Fig. 31.

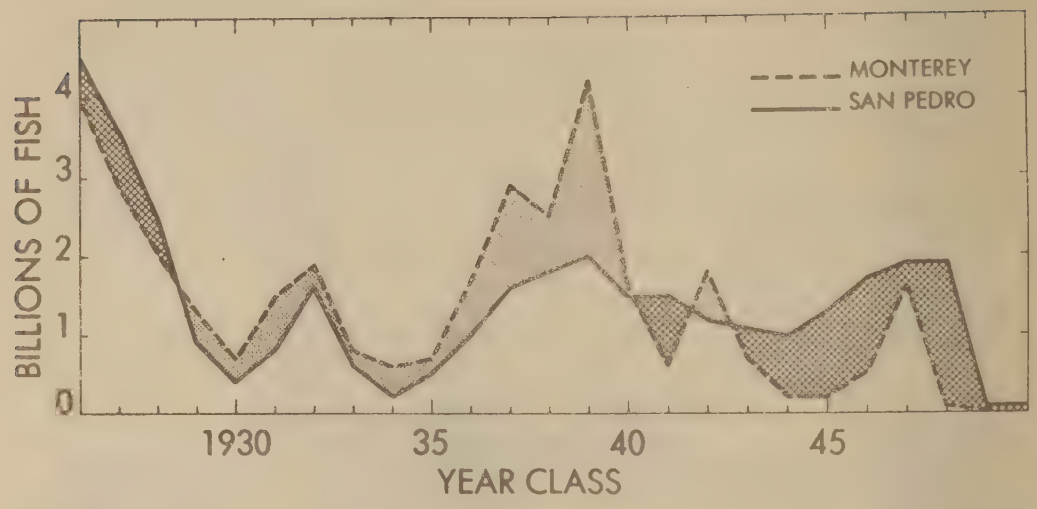

Fig. 33 Accumulated age estimates of sardine year class size at Monterey and San Pedro. Monterey estimates are weighted to San Pedro totals. Stippled areas indicate predominantly northern year classes; hatched areas indicate southern year classes. Based on data in Table XIV. See text (3.7) for explanation.

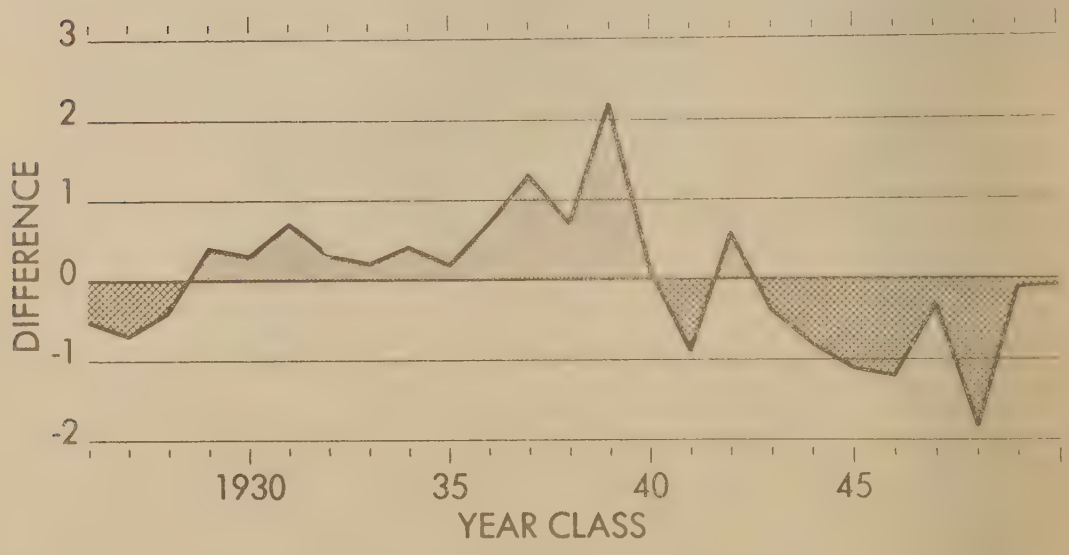

Fig. 34 Differences between the curves of Fig. 33.

in Fig. 34. The 1933, 1935, 1940, 1949 and 1950 classes tended to be of the same relative abundance at both ports. The 1929 through 1932, 1934, 1936 through 1939 and 1942 classes were relatively more abundant at Monterey than at San Pedro, the 1937 and 1939 classes were markedly so. The 1926 through 1928, 1941 and 1943 through 1948 classes were relatively more abundant at San Pedro. The 1945, 1946 and 1948 classes were markedly so.

To the extent that the two series overlap, the data of Figs. 32 and 34 may be compared. In general, the two figures show more similarites than dissimilarities. Outstanding differences occur in the 1931, 1932 and 1942 classes. In the British Columbia - San Pedro comparison, these year classes were relatively more abundant at San Pedro, whereas in the Monterey - San Pedro comparison these year classes were relatively more abundant at Monterey.

On the basis of these comparisons, it is obvious that the various year classes have not had the same relative abundance in all areas. That is, some year classes such as that of 1939 tend to be relatively more abundant to the north, and other year classes, such as that of 1948, tend to be relatively more abundant to the south. What could account for this difference in distribution? It has already been suggested in an earlier section that certain attributes of the sardine, and particularly time-connected changes in these attributes, could be explained on the basis of the area of year class origin. This could also account for the difference in year class distribution. The evidence bearing on the area of origin of year classes will be marshalled later.

3.8 Population size estimates

Population size, as well as year class size, may be estimated by the accumulated age method. The accumulated age population estimate for a particular season, for example, consists of all the fish caught in that season plus all fish caught in subsequent seasons from those year classes present in the fishery in the initial season. As was true for the accumulated age year class estimates, these estimates of population size are obviously minimal.

Since age one was by far the most common age at first (not full) recruitment, only age one and older fish were considered in the population size estimates. That is, even though zero ring fish were present in a particular season, members of that year class were not included in the population estimate for that particular season (although they were, of course, included in the estimates for subsequent seasons). This convention introduced little, if any, bias at any of the ports except British Columbia. At the latter port, fish were first recruited at earlier ages in the later seasons than in the earlier seasons. Thus, the population estimates for the earlier seasons in British Columbia tend to be too great with respect to the number of fish exposed to the fishery, but not with respect to the number of fish in the population (i.e. in the sea).

Accumulated age estimates of population size are given in Table XV and shown in Figs. 35 and 36[26] (see also estimates of spawning population size in Table XIII). The total estimates, based on landings at all four ports (Fig. 35), included the 1940-41 through 1956-57 seasons. Population size was at its highest level during this period in the 1940-41 season, declined to 1946-47, rose to 1949-50 and declined thereafter. Population sizes during the last seasons of the series were exceedingly small, on the basis of these estimates.

Table XV

ACCUMULATED AGE ESTIMATES OF SARDINE POPULATION SIZE, BASED ON ONE-RING AND OLDER FISH (in millions of fish)[27]

Season	British Columbia	San Francisco	Monterey	San Pedro	Total
1932-33	-	-	3,220	2,506	-
1933-34	-	-	4,178	3,588	-
1934-35	573	-	3,975	3,444	-
1935-36	489	-	3,048	2,469	-
1936-37	390	-	2,469	2,038	-
1937-38	525	-	2,466	2,160	-
1938-39	711	-	3,879	2,859	-
1939-40	900	-	4,149	3,179	-
1940-41	1,478	3,894	5,492	4,289	15,153
1941-42	1,548	3,530	5,452	4,135	14,665
1942-43	1,160	2,223	3,571	4,150	11,104
1943-44	854	1,734	3,550	3,446	9,584
1944-45	480	1,152	2,586	3,341	7,559
1945-46	214	475	1,056	2,860	4,605
1946-47	68	39	347	2,700	3,154
1947-48	52	82	547	2,826	3,507
1948-49	-	240	1,592	3,913	5,745
1949-50	-	245	1,277	4,877	6,399
1950-51	-	126	347	3,302	3,775
1951-52	-	-	160	1,096	1,256
1952-53	-	-	57	601	658
1953-54	-	-	-	1,121	1,121
1954-55	-	-	-	1,274	1,274
1955-56	-	-	-	852	852
1956-57	-	-	-	405	405

26/ These estimates differ from those given by Clark and Marr (1955) because (a) their estimates did not include one-ring fish; (b) the landings prior to the 1940-41 season at San Francisco, for which no age composition data are available, were "aged" by them on the basis of the age composition at Monterey.

27/ Data from sources indicated in Table I.

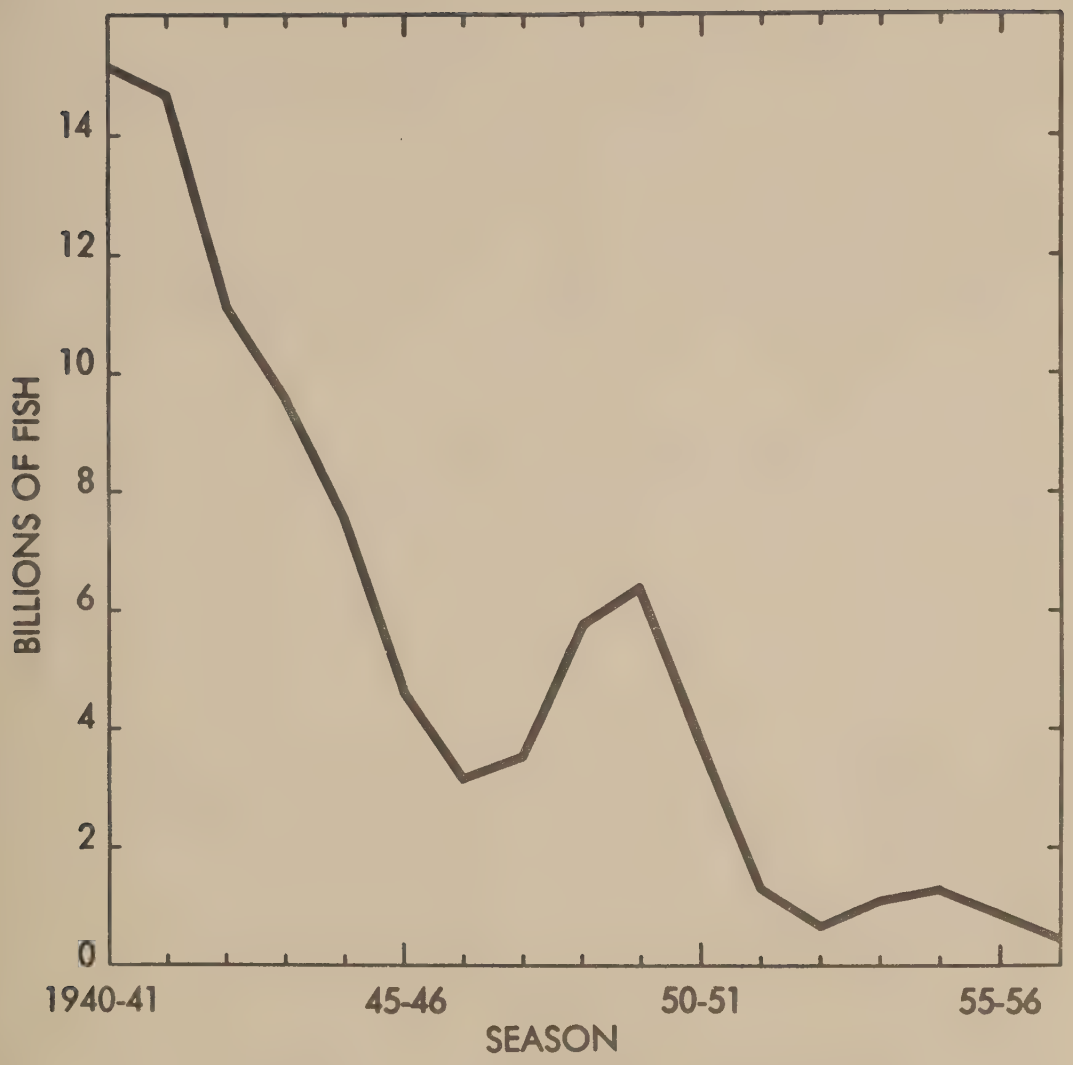

Fig. 35 Accumulated age estimates of sardine population size, all ports combined. Data from Table XV.

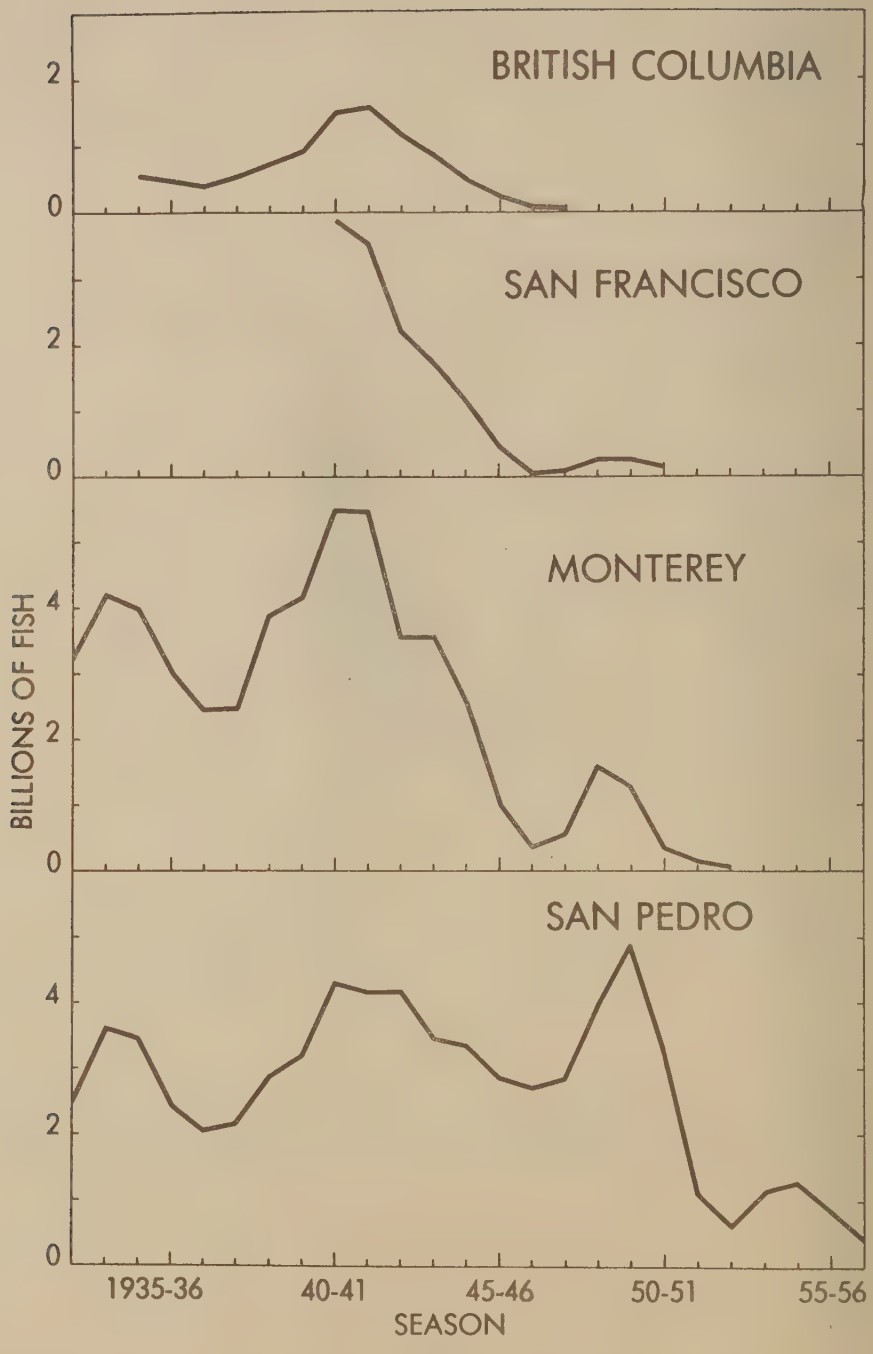

Fig. 36 Accumulated age estimates of sardine population size at British Columbia, San Francisco, Monterey and San Pedro. Data from Table XV.

Accumulated age estimates of population size by ports are shown in Fig. 36. They are available for the 1934-35 through 1947-48 seasons in British Columbia, the 1940-41 through 1950-51 seasons at San Francisco, the 1932-33 through 1952-53 seasons at Monterey, and the 1932-33 through 1956-57 seasons at San Pedro.

In British Columbia the curve of population size rose from the 1934-35 seasons to 1941-42 and declined to 1947-48. The curve for San Francisco declined from the 1940-41 seasons to a low level in 1946-47, which was essentially maintained through 1950-51. At Monterey, the curve exhibits peaks in 1933-34, 1940-41, 1941-42 and 1948-49, and lows in 1936-37, 1946-47 and 1952-53. At San Pedro the curve of population size has peaks in 1933-34, 1940-41, 1949-50 and 1954-55, and lows in1936-37, 1946-47, 1952-53 and 1956-57.

The occurrence of large population estimates is associated with the entrance of dominant year classes into the population, as may be seen by comparing Figs. 30 and 36. As indicated for several other attributes, estimates of population size have essential similarities between ports as, for example, the occurrence of high population levels. But again, there are relative differences between ports. For example, whereas the highest population level occurred in the 1940-41 season in the northern ports, it occurred in the 1949-50 season at San Pedro.

4 EFFECTS OF A FISHERY UPON A POPULATION

Historically, in considering variations in the yield of a fishery and, presumably, in the size of the population upon which the fishery is based, it has been customary to devote a major share of the investigations to the effects of the fishery on the population. Among the reasons for this emphasis are : (a) the fishery is more readily studied than the environment; and (b) the fishery is, generally, the only major variable introduced by man. As such, it may logically be expected to be an important factor in influencing population size.

I shall now consider in general the possible effects of a fishery on a population and then, in relation to the sardine fishery, the qualitative and quantitative observations made.

4.1 Kinds of effects

A fishery may be expected to have several kinds of effects on a population. Some are simply events which occur (in a cause and effect sense), but have no portent insofar as the long term yield of a fishery is concerned, while others involve relationships which, in certain instances, may be utilized in achieving a desired condition, such as maximizing the yield. Some of these effects have, in the past, been contemplated on a qualitative, more or less intuitive basis, while others have been considered rather rigorously. The features which will be considered, and their relationships to a fishery, include average age and size, area occupied by a fishery, population size, yield per recruit relationship, density dependent growth rates, and density dependent year class size.

4.1.1 Average age and size

It can easily be shown that where the total mortality experienced by a population is increased, as by the imposition of a fishery on all age groups, the average age and size of the fish in the population will be reduced as compared to the average age and size obtaining in the unfished population. At one time the observation of this effect was considered to be evidence of "overfishing" or "depletion"28/. It is now generally realized that, of itself, a decrease in average age (and size) is of no particular value in anticipating the long-term yield of a fishery.

4.1.2 Area occupied by fishery

It has often been observed that as a fishery for a particular species develops, the range of the fishery continues to expand. In some fisheries this process has continued until the area of the fishery approximately coincides with the range of the species fished. Such extension of the range of a fishery was at one time regarded as evidence of overfishing. It is now generally realized that this condition, of itself, has no implications regarding the long-term yield of a fishery.

4.1.3 Population size

In order to reach an understanding of variations in the yield of a fishery and, presumably, concomitant changes in population size, it is necessary to obtain measures of relative or absolute changes in population size. A commonly used measure of relative population size is the catch per unit-of-effort. As mentioned earlier, catch per unit-of-effort is more strictly a measure of relative population density. However, under certain conditions relative population density is proportional to abundance. (A common method of estimating absolute population size is the mark and recapture method.)

It has been commonly observed in the course of the development of a fishery that, eventually, even though additional effort is added to the fishery, total yield (in numbers) does not increase proportionately (and may even decrease in weight), and catch per unit-of-effort accordingly declines. Although a decline in catch per unit-of-effort in numbers has been interpreted as an indication of overfishing, of itself, this condition has no implications concerning the long-term yield of a fishery, although it certainly may have short-term implications. A decline in catch per unit-of-effort in weight has also been interpreted as evidence of overfishing. This may certainly be the case, as will be discussed below.

28/ The early use of the term "overfishing" (and perhaps even some cases of current usage) was sometimes rather vague, with apparently no concise definition in the mind of the user. It is obvious that the yield of a fishery can be maximized. In some fisheries this may be possible through unrestricted fishing. In other fisheries it may be possible through some restriction upon the fishery. In the latter case, exceeding the restriction upon the fishery will reduce the yield below the maximum. This is the condition to which I refer as overfishing. Similarly, not attaining the restriction will also reduce the yield and result in underfishing. These definitions are neither original nor unique and are introduced here solely for clarity.

4.1.4 Yield per recruit relationships

It has been observed, most frequently in the case of demersal species, that the relationship between increase in weight of a group of fish through growth of individuals and the loss of weight through the death of some members of the group is such that man may act to maximize the yield of a fishery. This is possible when the relationship is such that the weight of a group of fish increases over a period of years because of relatively rapid growth rates and low death rates. Obviously, when this relationship is favorable, the yield (in weight) of a fishery can be maximized by concentrating the fishery on fish of the appropriate age to produce maximum weight. Catching them at younger or older ages will be inefficient, since their weight will be less.

The most efficient way to achieve the desired effect is the direct one; i.e. to control the age (size) at first capture. This is feasible in the case of, say, a trawl fishery, but not in the case of a hook-and-line fishery. Here the indirect method of controlling the total catch has been used. The rationale of this approach is that if one understands the yield per recruit relationship, the maximum total yield may be estimated (under certain conditions). Then, in situations where it is not possible to control the age at first capture, the same effect may be achieved by controlling the total catch appropriately.

4.1.5 Density dependent growth rates

It is obvious that older fish near the upper limit of their size are using their food intake primarily for maintenance, whereas younger fish that are still growing rapidly are using a larger fraction of their food intake to create new fish tissue; thus, populations consisting primarily of younger fishes will be more efficient converters of food to fish than will be populations of older fishes.

In addition, it has sometimes been observed that there exists intra-specific competition for food. The removal of older, inefficient fish from a population will make more food available for the younger fish. Under these conditions the growth rate of these younger fish may increase. Thus, when a density dependent growth rate obtains, the yield per recruit relationship may prove to be even more attractive than would otherwise be estimated.

4.1.6 Year class size vs. stock size

If, in a population, the sizes of year classes are a function of the sizes of the spawning stocks that produced them, and if the relationship is such that year class size is maximal at some particular spawning stock size, then it is obvious that year class sizes (and thus the population and the yield) can be maximized by keeping spawning stock size at the appropriate level. If, on the other hand, year class size is not a function of spawning stock size, then it is equally obvious that controlling spawning stock size will have no effect on year class size.

Thus, the year class size vs. stock size relationship and the yield per recruit relationship represent the two major possible conditions under which action can be taken to maximize the yield of a fishery. Yield per recruit relationships have received much more attention than

the former. Indeed, Ricker (1954) has stated : "Fishing changes the absolute and relative abundance of mature fish in a stock, and the effect of this upon the numberof recruits in future years has often been considered only in the most general manner. The points of view encountered usually range from an assumption of direct proportion between size of adult stock and number of recruits, to the proposition that number of recruits is, for practical purposes, independent of the size of the adult stock".

4.2 Effects of the fishery upon the sardine population

Clark and Marr (1955) concluded that the only possible way in which the fishery could have a long-term effect on the size of the sardine population was through the relationship, if any, between year class size and spawning stock size. They considered the yield per recruit relationship to be such that the fishery was already producing a maximum yield per recruit. There were considered to be no other possible mechanisms by which the fishery could produce long-term effects on population size.

It is therefore not pertinent to review earlier studies in which, for example, expansion of the area of the fishery was regarded as being of significance with respect to the long-term yield of the fishery. Parenthetically, I may repeat that it is obvious that a fishery does affect the characteristics of a population. The nature of such effects has been considered above. For example, it was observed that a decrease in average age is associated to some extent with an increase in effort in the sardine fishery.

The kinds of effects of the fishery upon the sardine population which I wish to consider here are those which have a long-term relationship to the size of the population and, hence, to the yield. These include (a) the yield per recruit relationship, (b) a model in which population growth is assumed to be density dependent (Schaefer, 1954) and, briefly, (c) the relationships between year class size and spawning stock size.

4.2.1 Yield per recruit relationship

Clark (1952) stated "Assuming a natural mortality of 20 per cent, which is the most reasonable average figure available for the sardine, any year class will gain more in weight than it will lose through natural causes until it is three or four years old". She apparently did not consider the added effects of fishing mortality and age at first capture.

Clark and Marr (1955) examined this problem in somewhat more detail. They used the sardine growth pattern observed at Monterey, and various combinations of (a) ages at first capture of one, two and three years; (b) annual natural mortality rates of 18 and 39 per cent, and (c) annual fishing mortality rates of 26 and 45 per cent, as a basis for yield per recruit curves. They also gave curves showing, for three instantaneous natural mortality rates, the yield per recruit over a range of instantaneous fishing mortality rates (with age at first capture of two years). Clark and Marr (1955) concluded: ".... under the conditions stated and from the standpoint of increase in weight alone, there is no gain in letting two-ring and older fish remain in the sea to grow larger; on the contrary, they will lose more weight through natural deaths than they will gain through growth".

More recently, Reid (MS) has re-examined sardine yield per recruit curves. His calculations were based on (a) the growth curves observed in British Columbia and at San Francisco, Monterey and San Pedro; (b) annual natural mortality rates of 10, 20, 40 and 60 per cent; (c) annual fishing mortality rates of 10, 20, 40 and 60 per cent; and (d) ages at first capture of one, two and three years. His results on the ages at first capture giving maximum yield, at the several ports and under varying combinations of fishing and natural mortality rates, are summarized in Table XVI.

Table XVI

AGES AT FIRST CAPTURE GIVING MAXIMUM YIELD PER RECRUIT FOR THE SARDINE 29/

Natural mortality		Fishing mortality 10	20	40	60
10	San Pedro	1	2	2	3
	Monterey	2	2	3	3
	San Francisco	1	2	3	3
	British Columbia	2	3	3	3
20	San Pedro	1	1	1	1
	Monterey	1	1	2	2
	San Francisco	1	1	2	2
	British Columbia	1	1	2	3
40	San Pedro	1	1	1	1
	Monterey	1	1	1	1
	San Francisco	1	1	1	1
	British Columbia	1	1	1	1
60	San Pedro	1	1	1	1
	Monterey	1	1	1	1
	San Francisco	1	1	1	1
	British Columbia	1	1	1	1

29/ Data from Reid (MS).

At natural mortality rates of 40 per cent and greater, the maximum yield is obtained with age at first capture of one year, at all ports and regardless of fishing mortality rate. At a natural mortality rate of 20 per cent, maximum yield is obtained with age at first capture of one year, except for the three northern ports at fishing mortality rates of 40 per cent and

greater. At a natural mortality rate of ten per cent, the maximum yield is obtained with age at first capture of one year only at San Pedro and San Francisco, and only at a fishing mortality rate of ten per cent. Thus, while the conclusion of Clark and Marr (1955) is verified, greatly amplified information is given by Reid (MS).

It is apparent from data given above (Figs. 14, 15 and 16) that sardines are not fully recruited at a single age; that is, strictly speaking, there is not a single age at first capture. Even though on the average year classes are fully recruited at age two at San Pedro, some fish are caught at earlier ages. By taking this fact into account and by expressing yield curves as a yearly percentage of the total yield, Reid (MS) found that observed yields at San Pedro corresponded most closely with an annual fishing mortality rate of 40 per cent and an annual natural mortality rate of 20 per cent.

4.2.2 Density dependent population growth (Schaefer's model)

Schaefer (1954 a) has presented a model in which it is assumed that population growth is density dependent (i.e. that population growth takes the logistic form), that fishing mortality is the major cause of changes in population size and that, hence, by controlling fishing removals from the population it is possible to maximize the yield. This implies that recruitment, i.e. year class size, is density dependent (or that environmentally produced variations in recruitment are small with respect to the density produced variations). Schaefer (1954 a, b, and 1957) has applied this model to the sardine fishery, the North Pacific halibut fishery, and the yellowfin tuna fishery of the eastern tropical Pacific.

Various features of this model have been commented on by Clark and Marr (1955), Beverton and Holt (1957), and Ricker (1958 a, b). Objections have been raised to (a) the assumption of symmetrical sigmoid population growth, and (b) the essentially instantaneous response of population size to mortality required by the model. However, I will not discuss here the assumptions of the model per se, since there is obviously room for disagreement, but rather to extend its application to the sardine fishery. Catch per unit-of-effort data were available to Schaefer only through the 1950-51 season (Clark and Daugherty, 1952). Such data are now available through the 1954-55 season (Clark, 1956).

The data and computations for the entire period, 1932-33 through 1954-55, are given in Table XVII, since they were not included in Schaefer's (1954) paper. The notation used is his. His Figs. 9 and 10 are shown, with the additional data, as my Figs. 37 and 38.

With regard to Fig. 37, one may question whether the proposed relationship may best be described by the particular parabola shown or, indeed, by any parabola at all. It will be noted that the points for two of the additional seasons have negative values of $\overline{f(P)}$, although the variation of these points from the fitted line does not differ from variation elsewhere in the plot. Such points arise from the fact that the decrease between successive "initial populations" is greater than can be accounted for by the catch. The source of such variation must lie in variations not accounted for by the model or in measurement (sampling) error.

Table XVII

"ESTIMATION OF EQUILIBRIUM CATCHES FOR THE POPULATION OF PACIFIC SARDINE," after Schaefer (1954)

Season	Catch $k_2 F_t \overline{P}$	Tons per boat mo. $U = k_2 \overline{P}$	$\overline{P}$	P_o	AP	Eq. catch $\overline{f(P)}$	Boat mos. F_t
1932-33	295,030	557	1,223,729	-	-	-	530
1933-34	387,490	636	1,397,292	1,310,510	+305,384	692,874	609
1934-35	638,580	835	1,834,495	1,615,894	+ 2,196	640,776	765
1935-36	632,060	638	1,401,686	1,618,090	-273,526	358,534	907
1936-37	791,330	586	1,287,442	1,344,564	-369,096	422,234	1,350
1937-38	498,400	302	663,494	975,468	-194,434	303,966	1,650
1938-39	670,530	409	898,573	781,034	+113,145	783,675	1,639
1939-40	687,860	405	889,785	894,179	- 5,493	582,367	1,452
1940-41	493,320	404	887,588	888,686	+ 46,138	539,458	1,221
1941-42	680,370	447	982,059	934,824	+102,160	782,530	1,522
1942-43	573,070	497	1,091,909	1,036,984	- 27,462	545,608	1,153
1943-44	579,130	422	927,134	1,009,522	- 84,585	494,545	1,372
1944-45	614,050	420	922,740	924,937	-131,820	482,230	1,462
1945-46	440,380	302	663,494	793,117	-293,299	147,081	1,458
1946-47	247,690	153	336,141	499,818	-242,769	4,921	1,619
1947-48	130,110	81	177,957	257,049	+ 21,970	152,080	1,606
1948-49	189,090	173	380,081	279,019	+297,693	486,783	1,093
1949-50	337,620	352	773,344	576,712	+ 61,516	399,136	959
1950-51	353,090	229	503,113	638,228	+ 57,122	410,212	1,542
1951-52	128,530	187	410,839	456,976	-240,572	-112,042	594
1952-53	4,520	10	21,970	216,404	-193,336	-188,816	466
1953-54	3,172	11	24,167	23,068	+148,298	151,470	296
1954-55	67,258	145	318,565	171,366	-	-	458

It is possible to add four additional points in Fig. 38. They all lie well to the left of the "estimated line of equilibrium conditions". (There is reason to believe that the points for the next three seasons, when available, will fall in this same general area). The array of points now appears to be varying about a horizontal line, rather than about the equilibrium line.

According to the model, equilibrium catches with these low numbers of effort units (as shown by the four most recent seasons) should be higher than any of record. Since they are to the left of the line (and considerably below where they "should" be), the population should be

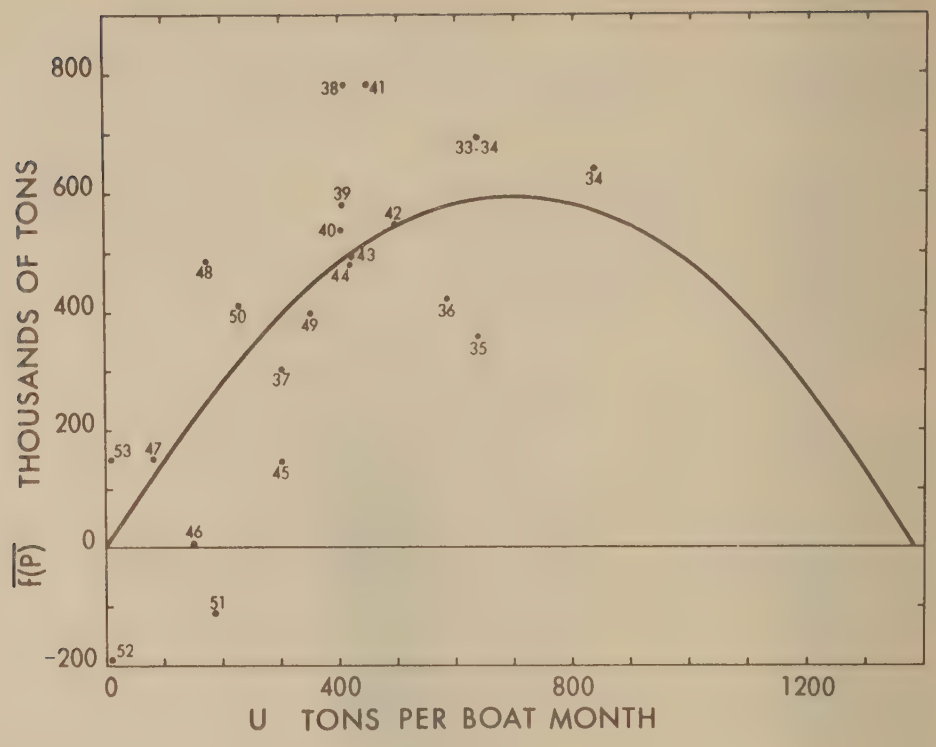

Fig. 37 Extension through 1953-54 season of Schaefer's (1954) plot of "Relationship between mean population and estimated equilibrium catch, California sardine".

increasing. There is no evidence that this is indeed the case. (The resurgence of the catch in the 1958-59 season, four seasons after the last included in Fig. 38, and eight seasons after the data fall to the left of the equilibrium line, may be attributed to the appearance of the apparently successful 1956 class and, probably, to an increase in availability).

As Schaefer (1954) has stated : "We may expect the data of commercial fisheries to correspond to the properties of the model if the assumptions underlying the model are fairly well fulfilled by the fisheries. The most basic assumption was that the growth of the fish population is a function of the size of the population and is not, therefore, subject to important variations due to other causes. If there exist other causes influencing the growth of the population of fish

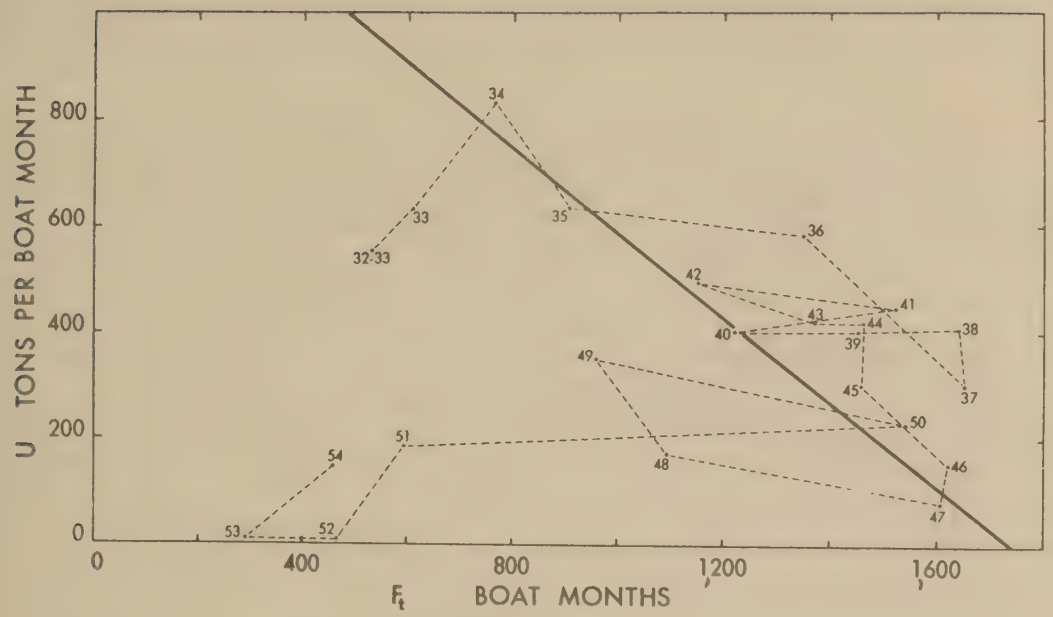

Fig. 38 **Extension through 1954-55 season of Schaefer's (1954) plot of "Relationship between intensity of fishing and mean population, California sardine".**

such as variations in the environment, which give rise to variations in the population growth and which are large in comparison to changes due to population size alone, we shall expect our plot of F_t, U to exhibit a quite different pattern. In this case we should have large changes in population size in either direction quite independent of antecedent changes in the amount of fishing. As a result, the increases or decreases in population will have little orderly sequence, except as they may be related to cyclic phenomena, and will bear little relation to the location of any line of average equilibrium conditions".

Thus, on empirical grounds, the model does not appear to correspond to the conditions obtaining in the sardine population. That is, the deviation, in Fig. 38, of the points for the last four seasons from the line fitted by Schaefer, indicate that population size is changing independently of the antecedent changes in the amount of fishing. In this case, the causes of

changes in population size must be changes in year class size independent of spawning stock size. Logically then, the causes of variations in year class size must be sought in the environment. As indicated, Schaefer's (1954) model does not appear to be applicable to the sardine.

4.2.3 Year class size vs. spawning stock size

A direct approach to examining the relationship between population growth, in numbers, and population size is to ascertain what relationship, if any, may be observed between year class size and spawning stock size. The difficulties associated with this approach include the facts that: (a) adequate series of the requisite data do not exist for very many species; and (b) year class and spawning stock sizes are difficult to measure and such measurements may include unrecognized error and/or bias In the case of species for which appropriate data are available, such comparisons have rarely, if ever, shown a relationship between year class size and spawning stock size. However, this in a sense constitutes negative evidence which, apparently, many individuals are unwilling to accept and which, certainly, does not preclude the possibility of such relationship for any population which has not been subjected to thorough examination, with appropriate data. There is also the possibility of obtaining a spurious correlation. Suppose, for example, that year class size is independent of stock size. If there are a series of small year classes, stock size will also be reduced as a consequence (e.g. Clark and Marr, 1955). If care is not taken to observe which occurred first, it might be erroneously concluded that year class size is a function of stock size.

The possible relationship between year class size and spawning stock size in the sardine was considered in some detail by Clark and Marr (1955) without, it must be remarked, concert. Marr observed that, while changes in population size were obviously attributable to changes in year class size, changes in spawning stock size had no demonstrable effect on year class size (over the range of stock sizes observed), and concluded that the causes of variations in year class size must be sought in the environment. Clark did not completely accept these observations and conclusions, but concluded (Clark and Marr, 1955) that a middling stock size "..... might correspond to the theoretical value..... at which the resulting year class is the least dependent on stock size, thus representing the optimum stock size for greatest recruitment. Below this range ..... year class size may be in part dependent on stock size because too few eggs are produced. Above this range year class size may again be partly dependent on stock size". She based her conclusion on two points : first, stock size and year class size were both large in the early part of the period for which data were available, and were both small in the later part of the period. This is certainly true; as already indicated, stock sizes are determined by year class sizes. Second, the largest year classes did occur at middling stock sizes. Again, as already indicated, the relationship is not significant.

In summary, the yield per recruit relationship and the possible relationsip between year class size and spawning stock size represent the two possible conditions (aside from unrestricted fishing), under which action can be taken to maximize the yield. The yield per recruit relationships at the several ports are such that maximum yield at ages at first capture greater than one year tend to obtain only at low natural mortality rates and high fishing mortality rates. The size of additions to the population cannot be shown to be a function of population size by the

application of Schaefer's (1954) model, nor by direct examination of data on year class size and spawning stock size.

5 EFFECTS OF ENVIRONMENT ON POPULATION SIZE

If, in the long-term, the fishery has little or no effect in controlling population size in numbers, that is, if year class size is not a function of spawning stock size, then the cause of variations in year class size and, hence, stock size, must be sought in the environment. Before considering such a relationship, it is pertinent to review at least the physical environment of the region. According to Reid et al (1958) :

"The California Current system is a part of the great clockwise circulation of the North Pacific Ocean. At high latitudes the waters move eastward under the influence of the strong westerly winds (the 'roaring forties') and near the coast of North America divide into two branches. The smaller part turns northward into the Gulf of Alaska, and the larger part turns southeastward to become the California Current. In general, the temperatures in the open ocean are lower toward the north so that the branch turning northward into the Gulf of Alaska is known as a warm current. The water which is brought south by the California Current system is cooler than the waters farther offshore. As it moves slowly south at speeds generally less than half a knot, it becomes warmer under the influence of the sun and by mixing with the warmer waters to the west. As it nears the latitude of 25°N, it begins to turn westward and its waters become part of the west-flowing North Equatorial Current. On the shore side of the current, some disturbances in the circulation are found.

"A small eddy is usually found offshore from Cape Mendocino through most of the year . . . . . A similar eddy is found between Guadalupe Island and the mainland. A permanent eddy, the Southern California Countercurrent . . . . . , is found inside the submerged peninsula that extends southeast from Point Conception and includes Santa Rosa Island, San Nicolas Island, and Cortes Bank. The waters on the eastward side of this are protected from the northwest winds by the land and separated in part from the strong southeasterly flowing offshore current. The currents are weaker and usually to the north. The waters remain off the coast of southern California for a considerable time and become much warmer than those offshore, which are constantly replaced by cooler water from the north".

Further : "A deep countercurrent, below 200 meters, flows to the northwest along the coast from Baja California to some point beyond Cape Mendocino. It brings warmer, more saline water great distances northward along the coast. When the north winds are weak or absent in late fall and early winter the countercurrent forms at the surface well on the inshore side of the main stream and extends from the tip of Baja California to north of Point Conception, where it has been called the Davidson Current".

And : "The process of upwelling, in which winds parallel to the coast move the waters offshore, has been mentioned. This effect seems to be intensified south at capes and points which extend out with the stream. Thus, Cape Mendocino, Point Conception, and Punta Eugenia are regions of more intense upwelling than the rest of the coast".

Some efforts to describe a relationship between year class size and environment have been made, involving temperature (Sette, unpublished manuscript), salinity (Walford, 1946), area of successful spawning (Marr, 1958, 1960, In press), and temperature and currents (Sette, 1960).

I wish to consider the models presented by others before elaborating on the one I have elsewhere presented in brief. While it will be apparent that I am not in complete agreement with the models previously presented, it is my intent to offer only constructive criticism. Indeed, I believe that, at least in part, the various models can be reconciled.

It is significant to note that, although I have considered the long-term effect of the fishery upon population size, Sette and Walford have not. They have made the tacit assumption that year class size, and hence population size, is a function of the environment and not of stock size.

5.1 Temperature

In about 1938 or 1939, Sette (unpublished manuscript) suggested that the above average year classes were associated with years of above average surface temperatures, and that below average year classes were associated with years of below average surface temperatures. The rationale for such a relationship was that in years of above average temperature, spawning would be spread over a greater area and a greater period of time. This condition, through a number of circumstances such as decreased competition and predation, would lead to greater survival and larger year classes. There were, however, some uncertainties connected with this study. For example, since age determinations were not available, it was necessary to identify dominant and subdominant year classes and their natal year from an inspection of length frequency distributions.

Since the work was not published, there seems to be little point in going into greater detail. I introduce the reference primarily to give proper credit for the basic ideas involved.

5.2 Salinity (Walford's model)

Walford (1946) observed a highly significant positive association between the size of the 1934 through 1941 classes and surface salinity. Relative year class size was estimated by the number of fish caught at age three. Salinity was measured as the average surface salinity for the months of June, July and August at La Jolla, California (Scripps Pier). This comparison may now be extended through 1955. Salinity data at Scripps Pier have been made available through the courtesy of Mrs. Margaret Robinson, Scripps Institution of Oceanography (for most of these data, see U.S. Coast and Geodetic Survey, 1958). Data on the sizes of the 1934 through 1955 classes have been presented in Table XIV and Fig. 28. The latter differ somewhat from those used by Walford, as may be seen in Fig. 39, but do correspond in general.

Data on average surface salinity at Scripps Pier, June through August, and on year class size, are shown in Fig. 40 for 1934 through 1955. The high positive association observed by Walford for 1934 through 1941 does not obtain subsequent to 1941. In fact, the association for

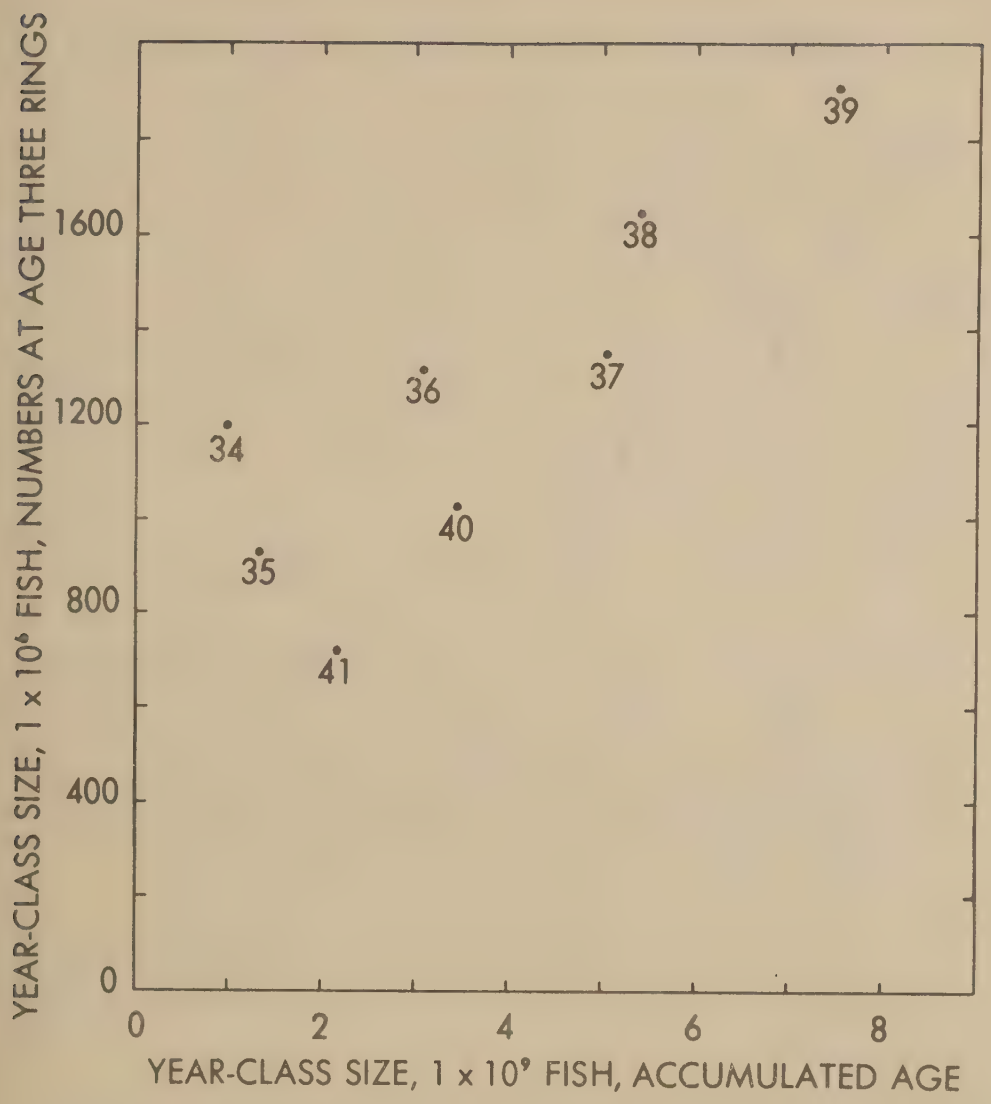

Fig. 39 Comparison of estimates of sardine year class size based on accumulated age (X) and numbers at age three rings (Y). Data are from Table XIV and Walford (1946).

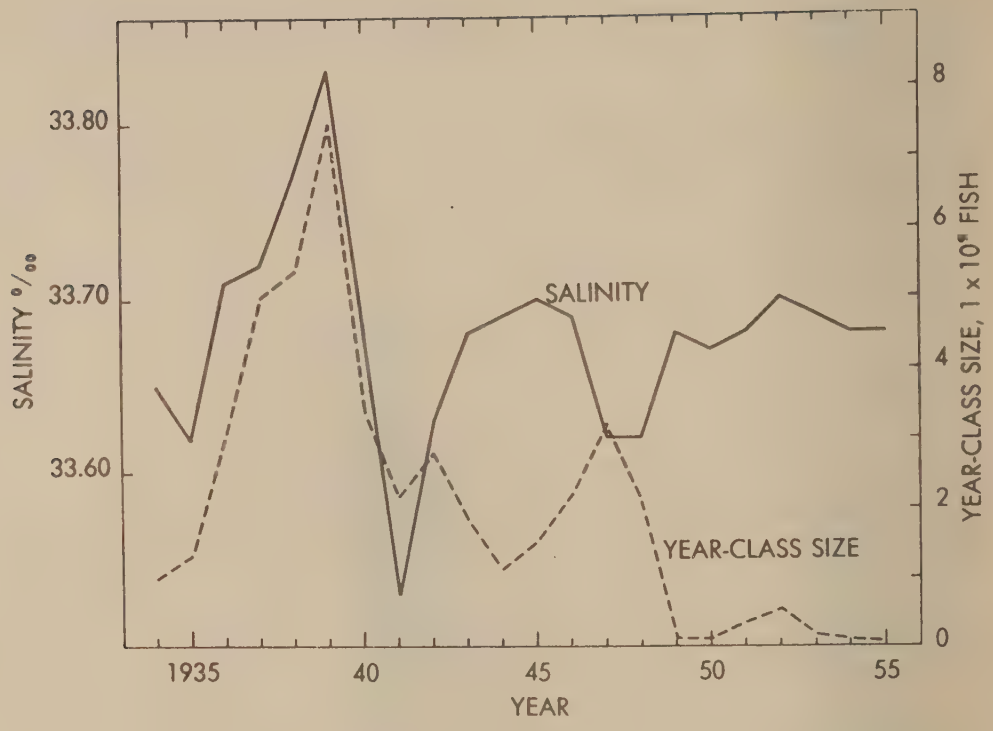

Fig. 40 Average surface salinity at Scripps Pier (June through August) and accumulated age estimates of sardine year class size. Data are from Table XIV, U.S. Coast and Geodetic Survey (1958), and Mrs. M. Robinson, Scripps Institution of Oceanography.

1942 through 1955 is negative. Year class size is plotted as a function of salinity in Figs. 41 42 and 43. The period 1934 through 1941 is shown in Fig 41. As shown by Walford (1946) the association is positive ($r = +0.845$; $P < .01$). The period 1942 through 1955 is shown in Fig 42. The association as indicated is negative ($r = -0.639$, $P < .02$). The data for the entire period, 1934 through 1955, are shown in Fig. 43. The association is positive ($r = +0.488$, $P < .05$).

The fact that a significant (by commonly accepted standards) positive association appears to exist for the entire period arises from the extremely close positive association for the 1934 through 1941 period. No biological significance may be attached to this statistic for the entire period. But what is the biological significance to be attached to the opposite relationships between salinity and year class size in the 1934-41 and 1942-55 periods? It can be argued that year class size is indeed a function of salinity and that because different conditions obtained in the ocean during the two periods, the nature of the functional relationship was reversed. In fact, evidence may be adduced to show that oceanic conditions were different during the early and late parts of this period (see 5.4). This, however, seems to be begging the question at hand.

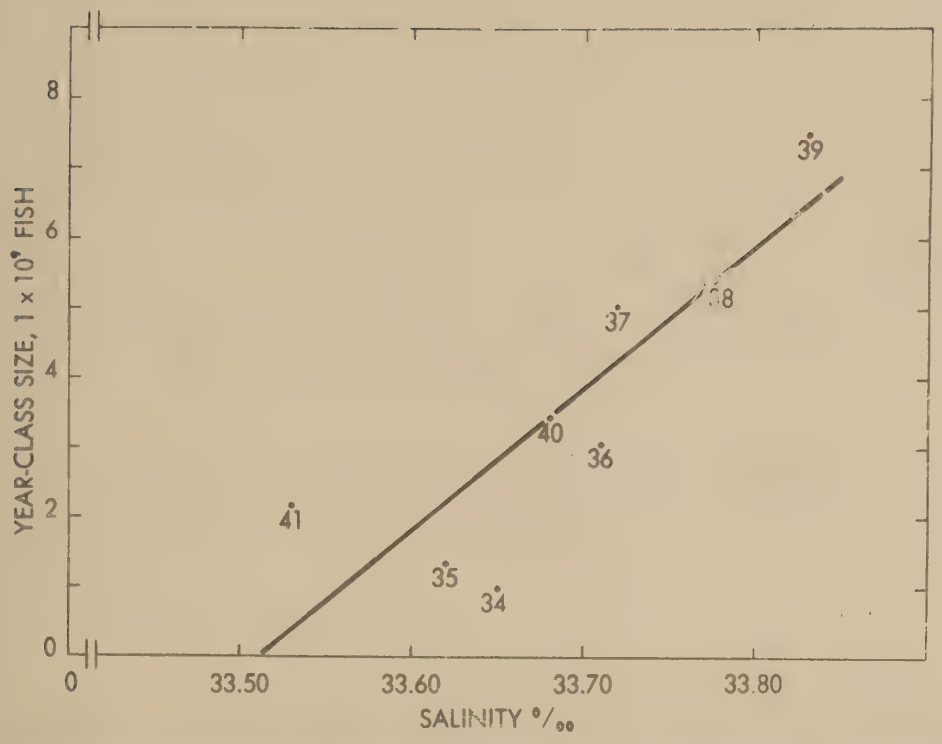

Fig. 41 Regression of accumulated age estimates of sardine year class size on average surface salinity at Scripps Pier (June through August), 1934 through 1941. Data are from sources indicated in Fig. 40.

Walford did not propose a functional relationship between salinity per se and year class size. Rather, he used salinity as an index of upwelling and stated (1946): "..... it is concluded that the salinity reflects the intensity of upwelling which brings up material nourishing the plankton; and it is suggested that the summer, when the aforesaid relationship is best demonstrable, is the most critical period in the life of the young sardine, when an abundant supply of food is most essential". I believe there are two fundamental objections, one practical, the other logical, to this line of reasoning. First, salinity at Scripps Pier was used as an index of upwelling; but high salinity at Scripps Pier may result from increased upwelling or advection of more western or southern water, while low salinity may result from decreased

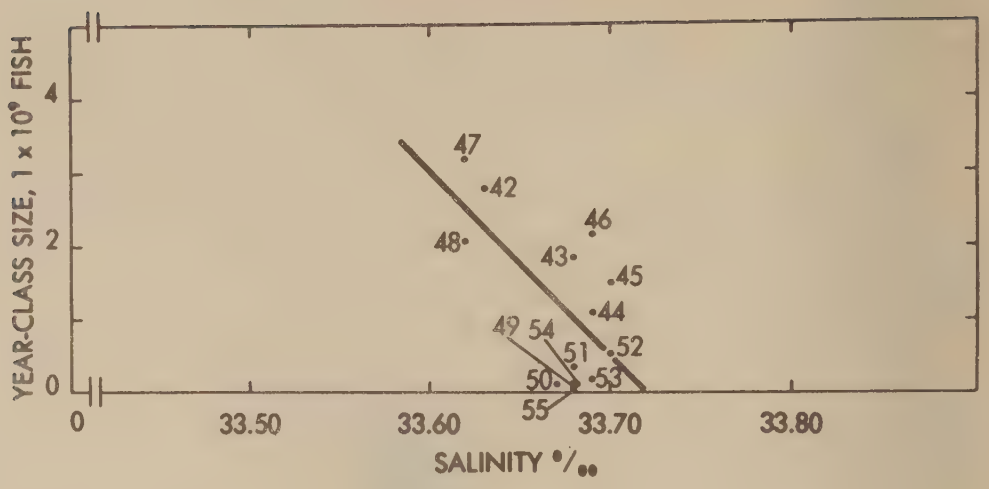

Fig. 42 Regression of accumulated age estimates of sardine year class size on average surface salinity at Scripps Pier (June through August), 1942 through 1955. Data are from sources indicated in Fig. 40.

upwelling or increased run-off. Second, if the chain of events "increased upwelling ---> increased nutrients ---> increased plankton production ---> increased year class size" is invoked as an argument to explain variations in sardine year class size, it must also apply to all other pelagic species in the same general ecosystem, lacking a priori reasons for assuming that increased basic production will affect different species differently.

There is no evidence that year class size in the ecological associates of the sardine vary in concert with sardine year class size, although it must be admitted that data on year class sizes are difficult to obtain 30/. Data on accumulated age estimates of year class size

30/ The statement has frequently been made that biological studies of fishes should ideally commence before a fishery starts, so that one may be better able to assess the effect of the fishery on the population. While this idea seems attractive, in practice there are a great many population characteristics that can be learned only (or at least most efficiently) through the operation of a fishery. In other words, much of the very information we would like to have about a virgin population is difficult or impossible to obtain prior to the inception of a fishery.

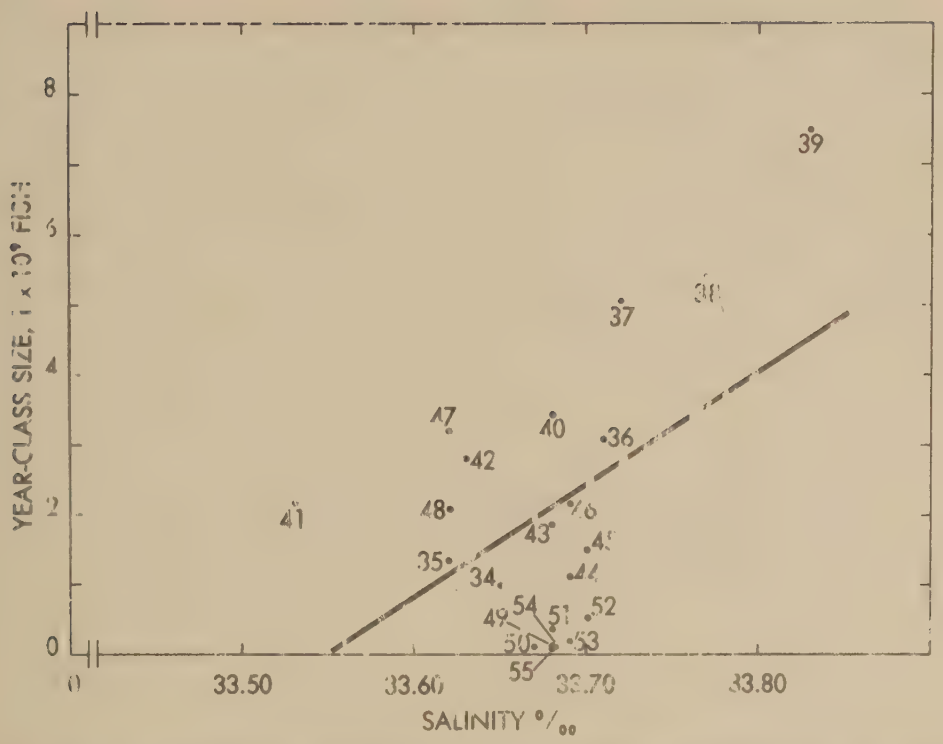

Fig. 43 **Regression of accumulated age estimates of sardine year class size on average surface salinity at Scripps Pier (June through August), 1934 through 1955. Data are from sources indicated in Fig. 40.**

of Pacific mackerel (Pneumatophorus diego) are given by Fitch (1958). These estimates and estimates of sardine year class size for the 1938 through 1955 classes are shown as time series in Fig. 44 and as a scatter diagram in Fig. 45. Obviously, there is no association in time between these two species with respect to year class size ($r = +0.15$, $P > .05$). Furthermore, data for the 1938 and 1952 through 1955 classes of Pacific mackerel are incomplete. Both the 1953 and 1955 classes of Pacific mackerel are large, although neither has yet completed its contribution to the fishery (in published data). Thus far, the 1953 class has been exceeded in size by only three other year classes and the 1955 class by only six other year classes. On the basis of the average percentage contribution by ages of 13 year classes, the 1955 class has made only about 35 per cent of its expected total contribution to the catch.

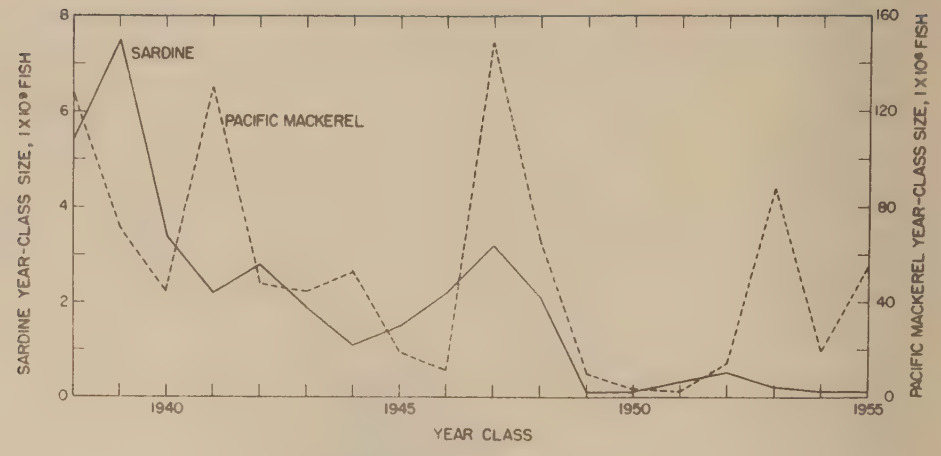

Fig. 44 **Accumulated age estimates of sardine and Pacific mackerel year class size. Data are from Table XIV and Fitch (1958). Data for 1938 and 1951 through 1955 classes of Pacific mackerel are incomplete.**

Adequate time series for other pertinent species are not available. There are, however, data on the age composition of the northern anchovy (Engraulis mordax) for the 1952-53 through 1956-57 seasons (Miller et al, 1955; Miller and Wolf, 1958). Although these data are of limited value in deriving accumulated age estimates of year class size, owing to changes in availability and economic demand, it is evident that the 1954 class was considerably larger than other year classes (see also Miller, 1956). Jack mackerel (Trachurus symmetricus) of the 1954 and 1958 classes were extremely abundant in the catch in their first year of life. On the basis of present knowledge, it is impossible to tell whether this was a reflection of large absolute abundance or exceptional availability.

In summary, the high positive association observed by Walford (1946) between sardine year class size and salinity did not obtain in subsequent years and was, in fact, reversed. There is a practical objection to using salinity at Scripps Pier as a measure of upwelling and a logical objection to the model in which increased upwelling results in increased sardine year class size. In fact, it may well be that the conditions which lead to increased upwelling also lead to decreased sardine year class size (see 5.4).

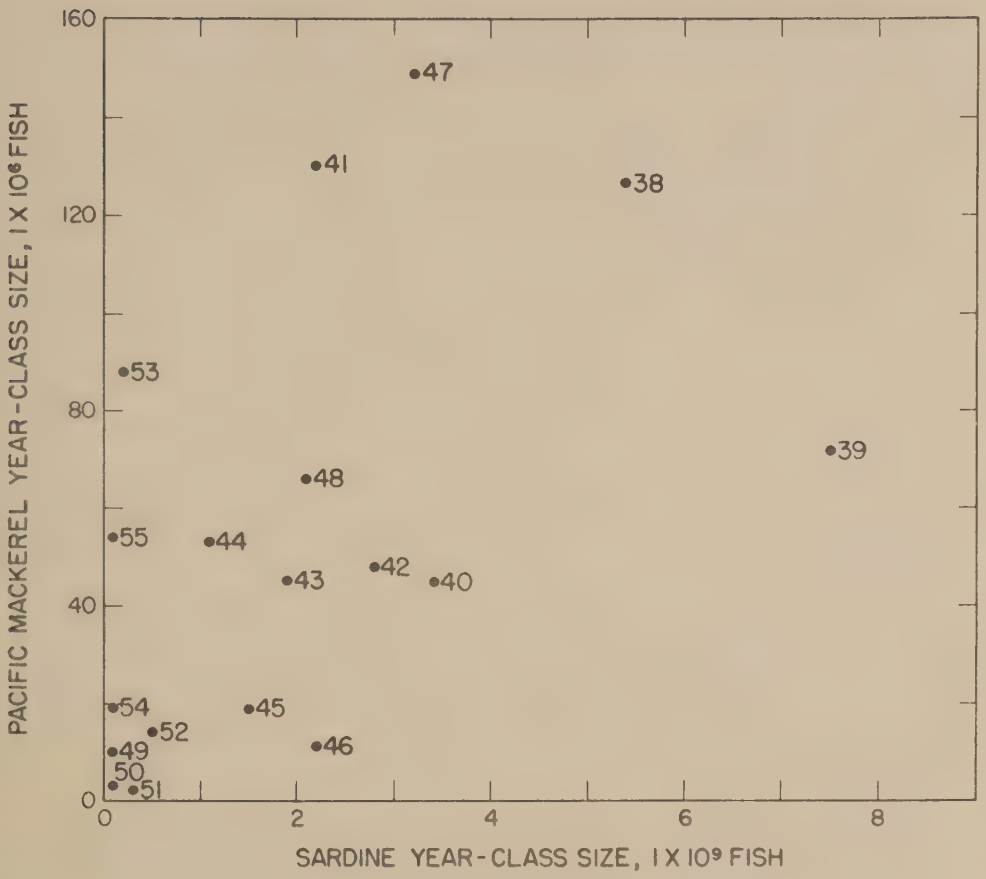

Fig. 45 Regression of accumulated age estimates of Pacific mackerel year class size on sardine year class size. Data are from Table XIV and Fitch (1958).

5.3 Temperature and currents (Sette's model)

Sette (1960) has presented a model which is intended to account for general levels of year class size over periods of time, but not for year to year variations about these levels. He postulates two requirements for the production of large year classes on the average :

(a) the opportunity for spawning over a considerable period of time, say March through June, as indicated by the presence of 15°C water. Temperature per se was not considered to be the requisite condition, but rather an indicator of a complex set of requisite conditions;

(b) circulation off southern California such that larvae are carried first southward from the spawning area, inshore and then northward. In other words, that the southern California eddy (Reid et al., 1958) be well developed. He further hypothesized that this eddy is better developed during periods of weak spring and summer northwesterly winds and less well developed during periods of strong northwesterly winds.

(Tibby, 1939, also suggested that the circulation pattern was of primary importance in determining year class size).

In order to examine his model, Sette used surface temperature data from Scripps Pier (December through February mean), an index of northwest winds along the California coast (June through August average), and accumulated age estimates of sardine year class size (from Clark and Marr, 1955). These data were plotted as time series extending, for at least one variable, over a 30 year period. During the early part of this period, temperatures tended to be high, winds weak and year class size large. During the later part of the period temperatures tended to be low, winds strong and year class size small. In 1957 and 1958, temperature and wind data indicate a return to the earlier conditions. (There was no association between the year to year variations of temperature, wind and year class size). Sette (1960) concluded that "Although this does not prove a cause and effect relationship, the long term events are consistent with the hypothesis .....".

The idea that spawning success is related, at least in part, to the degree of southern California eddy development, which in turn is related to the strength of northwesterly winds, is certainly intellectually attractive. Fortunately, data resulting from extensive CCOFI drift bottle experiments which began in 1954, permit examination of the degree of eddy development under different conditions of northwesterly winds and temperature. These data are unpublished, and have generously been made available to me by Mr. Hans Klein and Miss Carol Ryan of the Scripps Institution of Oceanography. (Data from the 1937 drift bottle experiment of Tibby (1939) are also available).

It is not clear to me whether Sette postulated that when the eddy is better developed more sardine larvae will be brought inshore, regardless of source, or that sardine larvae from farther offshore will be brought inshore, or both. In any case, if drift bottles are substituted for sardine larvae (which may be thought of as tiny drift bottles, although not necessarily drifting at the same level), one should expect to observe differences in recovery rates between years when the eddy is well developed and years when it is not well developed, provided that Sette's model is realistic.

The year 1958 was one of reduced northwesterly winds and high surface temperatures in which, presumably, the southern California eddy was well developed. The years 1955 and 1956, on the contrary, were ones of increased northwesterly winds and low surface temperatures in which, presumably, the eddy was poorly developed. Data on drift bottle releases and recoveries for the months of January through July, 1955, 1956, and 1958 are given in Table XVIII and shown in Fig. 46. They pertain to releases on three station lines more or less normal to the alongshore components of the eddy. There are no consistent differences between the results of the 1955 and 1956 experiments on the one hand and the 1958 experiment on the other, with respect to either (a) the rate of recovery, or (b) the distance offshore of releases from which recoveries were made. I conclude that the differences in the southern California eddy postulated by Sette (1960) either did not obtain in these three years or were not revealed by drift bottle experiments (see 5.4).

5.4 Area of successful spawning (Marr's model)

In a sense, all of these models deal with different and partial facets of the same complexity in nature. Their verisimilitude is related to the extent that they encompass all the important factors. This paper has so far dealt with characteristics of the fishery and of the biology of the sardine, and especially those characteristics that have not been extensively considered elsewhere. Any realistic model must explain these characteristics, or at least be consonant with them. It is pertinent, therefore, to summarise these characteristics.

(a) Location and magnitude of catch : The catch did not decline simultaneously in all areas of the fishery, nor was the extent of the decline the same in all areas. In general, the decline in catch occurred first in the Pacific Northwest and proceeded south. The history of the decline at San Pedro is unique, compared to the other ports.

(b) Year class composition of the catch : If the decline in catch was the result of a simple diminution of population size and contraction of range, one would not expect any marked changes in year class composition. A reduction in availability, for whatever reason, was certainly a factor in the decline in the British Columbia fishery. In addition, however, the 1943 class was the last year class to reach British Columbia in appreciable numbers and the remaining fishery was supported by year classes already in the population.

(c) Dominant age in the catch and age at full recruitment : Here again are area-specific differences. Only at San Pedro, for example, was a single age, two, clearly dominant. Age one was more frequently dominant at Monterey and San Francisco than at San Pedro. There are similar differences between ports in the age at full recruitment.

(d) Average growth during first year of life ($\bar{l}_1$) : The $\bar{l}_1$ at all ports for the 1943 and earlier classes fluctuated about a low level. There were no apparent area specific differences. For the 1944 and subsequent classes at San Pedro, the fluctuations are somewhat larger and about a much higher level. Such data as there are for the other ports for this later period suggest that the $\bar{l}_1$s may have passed through an intermediate level before attaining the new, high level.

Table XVIII

RECOVERIES OF DRIFT BOTTLES RELEASED OFF SOUTHERN CALIFORNIA IN 1955, 1956 AND 1958 [31/]

		Station numbers																
1955		27	28	30	32	35	37	40	43	45	50	55	60	65	70	80	90	
Stn. line	Month	-	-	-	-	-	-	2	14	22	42	62	82	102	122	162	202	miles off shore
83	Jan.	-	-	-	-	-	-	2	0	-	0	-	-	-	-	-	-	
	Feb.	-	-	-	-	-	-	2	0	-	0	-	[illegible]	-	-	-	-	
	Mar.	-	-	-	-	-	-	1	2	-	0	-	0	-	-	-	-	
	Apr.	-	-	-	-	-	-	6	3	-	0	-	0	-	0	-	-	
	May	-	-	-	-	-	-	7	2	-	0	-	-	-	-	-	-	
	June	-	-	-	-	-	-	7	1	-	0	0	0	-	-	-	-	
	July	-	-	-	-	-	-	6	3	-	0	0	0	-	-	-	-	
Total recovered								31	11		0	0	1		0			
Total released								84	84		84	24	60		12			
% recoveries								36.9	13.1		0	0	1.7		0			
		-	2	10	18	30	38	50	62	70	90	110	130	150	170	210	250	miles off shore
90	Jan.	-	7	2	-	1	0	-	-	0	-	-	-	-	-	-	-	
	Feb.	-	0	2	-	-	0	-	-	0	0	-	-	-	-	-	-	
	Mar.	-	7	4	-	-	1	-	-	0	0	-	0	-	-	-	-	
	Apr.	-	0	0	-	-	0	-	-	0	0	-	0	-	0	-	-	
	May	-	6	6	-	-	4	-	-	1	0	-	-	-	-	-	-	
	June	-	0	0	-	-	1	-	-	1	0	0	0	-	-	-	-	
	July	-	5	7	-	-	0	-	-	0	0	0	-	-	-	-	-	
Total recovered			25	21		1	6			2	0	0	0		0			
Total out			82	82		10	82			82	72	24	36		12			
% recoveries			30.5	25.6		10.0	7.3			2.4	0	0	0		0			
		-	-	2	10	22	30	42	54	62	82	102	122	142	162	202	242	miles off shore
97	Jan.	-	-	1	0	-	-	0	-	-	-	-	-	-	-	-	-	
	Feb.	-	-	0	0	-	-	2	-	-	0	-	-	-	-	-	-	
	Mar.	-	-	5	8	-	-	0	-	-	0	-	0	-	-	-	-	
	Apr.	-	-	-	-	-	-	0	-	-	0	-	0	-	-	-	-	
	May	-	-	8	0	-	-	0	-	0	-	-	-	-	-	-	-	
	June	-	-	2	0	0	-	1	-	0	0	0	-	-	-	-	-	
	July	-	-	0	0	0	-	0	-	0	0	0	-	-	-	-	-	
Total recovered				16	8	0		3		0	0	0	0					
Total out				72	72	24		84		36	60	24	24					
% recoveries				22.2	11.1	0		3.6		0	0	0	0					
1956		27	28	30	32	35	37	40	43	45	50	55	60	65	70	80	90	
Stn. line	Month	-	-	-	-	-	-	2	14	22	42	62	82	102	122	162	202	miles off shore
83	Jan.	-	-	-	-	-	-	0	0	-	0	-	0	-	-	-	-	
	Feb.	-	-	-	-	-	-	0	1	-	-	-	0	-	-	-	-	
	Mar.	-	-	-	-	-	-	4	2	-	0	-	0	-	-	-	-	
	Apr.	-	-	-	-	-	-	4	2	-	0	0	0	-	-	-	-	
	May	-	-	-	-	-	-	2	1	-	0	0	0	-	-	-	-	
	June	-	-	-	-	-	-	2	1	-	0	0	0	-	-	-	-	
	July	-	-	-	-	-	-	-	0	-	0	0	0	-	0	0	0	
Total recovered								12	7		0	0	0		0	0	0	
Total out								72	84		72	48	84		12	12	12	
% recoveries								16.7	8.3		0	0	0		0	0	0	
		-	2	10	18	30	38	50	62	70	90	110	130	150	170	210	250	miles off shore
90	Jan.	-	4	6	-	-	0	-	-	0	-	0	-	-	-	-	-	
	Feb.	-	0	3	-	-	0	-	-	1	-	0	-	-	-	-	-	
	Mar.	-	9	5	-	-	2	-	-	3	-	0	-	-	-	-	-	
	Apr.	-	6	1	-	-	0	-	-	0	-	0	0	-	-	-	-	
	May	-	0	0	-	-	4	-	-	1	0	-	-	-	-	-	-	
	June	-	3	2	-	-	4	-	-	3	3	-	-	-	-	-	-	
	July	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	
Total recovered			22	18			10			9	3	0	0					
Total out			72	84			72			84	24	48	12					
% recoveries			30.6	21.4			13.9			10.7	12.5	0	0					

(Continued)

Table XVIII (Continued)

		Station numbers																
		27	28	30	32	35	37	40	43	45	50	55	60	65	70	80	90	
		-	-	2	10	22	30	42	54	62	82	102	122	142	162	202	242	miles off shore
97	Jan.	-	-	0	0	-	-	0	-	-	0	-	-	-	-	-	-	
	Feb.	-	-	0	2	-	-	0	-	-	0	-	-	-	-	-	-	
	Mar.	-	-	0	0	-	-	0	-	-	0	-	-	-	-	-	-	
	Apr.	-	-	1	0	-	-	0	-	-	0	-	0	-	-	-	-	
	May	-	-	0	0	-	-	0	-	0	0	-	-	-	-	-	-	
	June	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	July	-	-	-	0	-	-	0	-	0	0	-	-	-	-	-	-	
Total recovered				1	2			0		0	0							
Total out				60	72			72		24	72		12					
% recoveries				1.7	2.8			0		0	0		0					

1958		27	28	30	32	35	37	40	43	45	50	55	60	65	70	80	90	
Stn. line	Month	-	-	-	-	-	-	2	14	22	42	62	82	102	122	162	202	miles off shore
83	Jan.	-	-	-	-	-	-	-	3	-	5	0	1	-	-	-	-	
	Feb.	-	-	-	-	-	-	-	2	-	0	0	-	-	-	-	-	
	Mar.	-	-	-	-	-	-	1	3	-	1	0	0	-	1	0	-	
	Apr.	-	-	-	-	-	-	-	2	-	0	0	0	-	0	0	-	
	May	-	-	-	-	-	-	3	2	-	0	0	0	-	0	0	0	
	June	-	-	-	-	-	-	11	0	-	0	0	0	-	0	0	0	
	July	-	-	-	-	-	-	4	0	-	0	0	0	-	0	0	0	
Total recovered								19	12		6	0	1		1	0	0	
Total out								48	84		84	84	72		60	60	36	
% recoveries								39.6	14.3		7.1	0	1.4		1.7	0	0	

		-	2	10	18	30	38	50	62	70	90	110	130	150	170	210	250	
90	Jan.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Feb.	0	0	0	-	-	2	-	-	0	0	-	-	-	-	-	-	
	Mar.	-	9	9	-	-	3	-	-	2	3	0	0	-	0	0	0	
	Apr.	-	7	0	-	-	0	-	-	0	0	0	0	-	0	0	0	
	May	-	2	8	-	-	0	-	-	0	-	0	0	-	0	0	0	
	June	-	6	6	-	-	0	-	-	0	0	-	0	-	0	0	0	
	July	-	8	2	-	-	0	-	-	0	0	0	0	-	0	0	0	
Total recovered			32	25			5			2	3	0	0		0	0	0	
Total out			72	72			72			72	60	48	60		60	60	60	
% recoveries			44.4	34.7			6.9			2.8	5.0	0	0		0	0	0	

		-	-	2	10	22	30	42	54	62	82	102	122	142	162	202	242	
97	Jan.	-	-	0	2	-	-	0	-	-	0	-	-	-	-	-	-	
	Feb.	-	-	0	0	-	-	0	-	0	0	-	-	-	-	-	-	
	Mar.	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	-	
	Apr.	-	-	4	0	0	-	0	-	0	0	-	0	-	0	0	-	
	May	-	-	1	0	0	-	0	-	0	0	-	0	-	0	0	0	
	June	-	-	1	-	0	-	0	-	0	0	-	0	-	0	0	0	
	July	-	-	2	0	0	-	0	-	0	0	0	0	-	0	0	0	
Total recovered				8	2	0		0		0	0	0	0		0	0	0	
Total out				72	60	48		72		60	72	12	48		60	60	36	
% recoveries				11.1	3.3	0		0		0	0	0	0		0	0	0	

1/ Data from the files of the Scripps Institution of Oceanography, made available by H. Klein and C. Ryan.

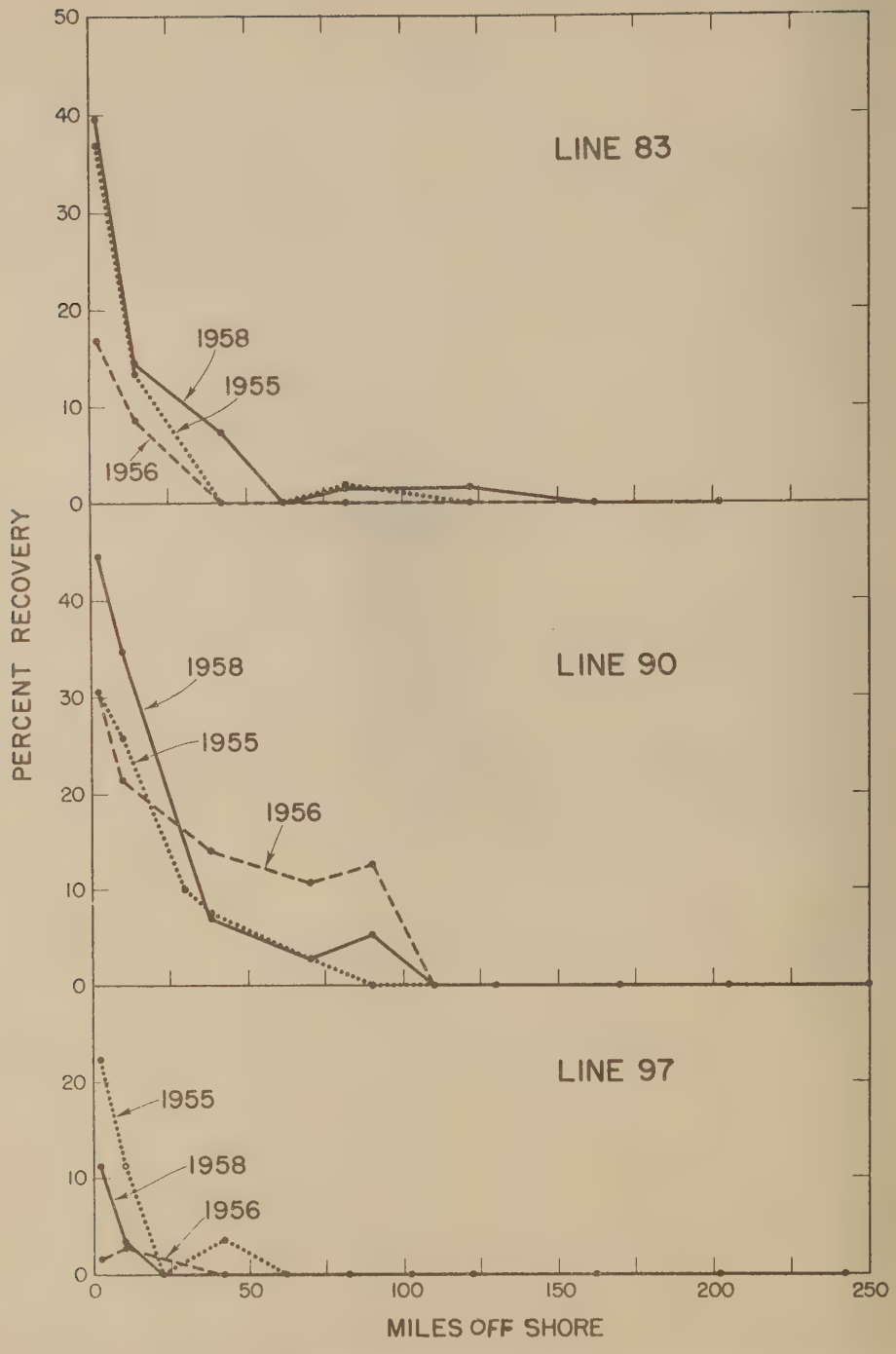

Fig. 46 Recoveries of drift bottles, as a function of distance off shore of point of release, released off southern California in 1955, 1956 and 1958. Data are from H. Klein and C. Ryan, Scripps Institution of Oceanography.

(e) Growth (length-on-age) curves : There are area-specific differences in growth curves. The curve for British Columbia is consistent and at a high level at ages three and more. The curve for San Pedro is at a low level at early ages and shifts toward the British Columbia curve starting at age seven. The Monterey and San Francisco curves resemble the British Columbia curve through age three, are intermediate between British Columbia and San Pedro at ages four and five, and shift toward British Columbia at age six.

(f) Movements as revealed by tagging : Extensive tagging experiments (pre-World War II) have shown that fish tagged off southern California, central California and the Pacific Northwest were recovered in all areas. However, 75 per cent of the fish tagged off Baja California were recovered in southern California, and secondarily off central California. Only one recovery was made in the Pacific Northwest.

(g) Spawning areas : There are at present four spawning areas : off southern California, off central Baja California, along southern Baja California, and in the Gulf of California. The area off southern California may expand to the north in some years.

(h) Year class size : There are area-specific differences in year class sizes as measured by accumulated age estimates at the different ports. Absolute differences would be expected, but there are also relative differences. Thus, the 1939 class was relatively more abundant in the north, while that of 1948 was relatively more abundant in the south.

Can an explanation be offered that will take into account these features of the fishery and the population? A model I have previously proposed (Marr, 1960, In press) may offer such an explanation. Its essential features are :

(a) Sardines produced on the spawning grounds off southern California and central Baja California make up the bulk, or all, of the United States and Canadian catch. (I am omitting from consideration fish produced on the southern Baja California and Gulf of California spawning grounds. This implies either that fish from these areas do not contribute substantially to the catch or, if they do, that their contributions account for discrepancies between what would be expected on the basis of the model and what was actually observed.)

(b) Sardines produced on the southern California spawning grounds migrate as far north north as British Columbia, support the fishery there and contribute to the fisheries at San Francisco, Monterey, and San Pedro.

(c) Sardines produced on the central Baja California spawning grounds migrate as far north as central California and contribute to the fisheries at San Francisco, Monterey and, especially, San Pedro.

(d) Lack of spawning success on the southern California spawning grounds, since 1943, could thus account for the observed changes in the fishery.

(e) Coincident with this postulated lack of success on the southern California spawning grounds, there was a period of below average surface temperatures. I do not necessarily wish to imply that temperature per se is responsible for variations in spawning success, but rather to use it, for the moment, as an indicator of general climatic conditions that do control spawning success. The nature of this relationship is discussed below.

I have listed eight general features of the fishery and the population. I now wish to consider how these relate to the model :

(a) Location and magnitude of catch : If for practical purposes the last successful spawning off southern California was in 1943, one would expect:

(i) a general decline in total catch, and
(ii) a progressive decline from south to north.

There are exceptions to these generalizations, but these are not necessarily in conflict with the model. For example, in the face of a general decline in catch, the 1950-51 catch at San Pedro was the largest on record. But about half of this catch was contributed by the 1948 class, which has been characterized as a predominantly southern year class. (As a result of reduced population size and below average temperatures there may well have been a contraction of range to the south, superimposed on what the model predicts.)

(b) Year class composition of the catch : Again, if no year classes were produced off southern California subsequent to 1943, it would be expected that all of these year classes would be absent in the Pacific Northwest and in reduced numbers elsewhere, especially in central California.

(c) Dominant age in the catch and age at full recruitment : It would be expected on the basis of distance, and is borne out by tagging experiments, that it requires a longer period of time for the fish from the central Baja California spawning area to reach the San Pedro fishery than it does for the fish from the southern California spawning grounds to reach the central California fishery. Thus, age one is more frequently dominant at Monterey and San Francisco than at San Pedro. Age two is clearly the dominant age at San Pedro. The fact that the most common age at full recruitment at Monterey is three could be a reflection of the increasingly greater northward migration of southern year classes with increasing age.

(d) Average growth during first year of life ($\bar{l}_1$) : It is obvious that in 1943 and earlier years the fish experienced a different growth history during their first year of life than they did in 1944 and subsequent years. While these differences might be attributed to differences in time of spawning on the two spawning grounds or to density dependence (year class size), I believe they may be attributed to differences in the amount of food available (density independent). When spawning is successful in the two areas, it commences at about the same time (see evidence below), so that essentially the same amount of time should be available for growth during the first year in the two areas. The question of density dependent growth has been considered earlier. The amount of food available may vary widely, however. Data on plankton volumes have been presented (South Pacific Fishery Investigations, 1952 et seq., and Thrailkill, 1956). Reid et al. (1958) have compared plankton volumes and temperature over an area off southern California and northern Baja California. A negative association exists, such that an average volume of about 200 cc/1000 M^3 at 15°C would be tripled by a decrease of 0.5°C or halved by an increase of 0.5°C.

Thus, in the warm years when successful spawning was possible in both areas, plankton volumes were low and there was less food per fish. On the other hand, in the more recent cool years, when it is postulated that successful spawning was possible only in the area off central Baja California, plankton volumes were high and there was more food per fish. (Although there are large changes in plankton composition from year to year, I assume that in general, as plankton volumes increase, the constituents that are sardine food also increase in volume.)

(e) Growth (length-on-age) curves : Even though growth during the first year of life tends to be similar, it is to be expected that during the course of their life, fish produced on the central Baja California spawning grounds will, on the average, experience warmer temperatures than will fish produced on the southern California spawning grounds. Thus, it may also be expected that their growth histories will show concomitant differences. The southern fish may be expected to have a more accelerated existence and grow more rapidly during early years, but have a reduced longevity. Northern fish may be expected to have a slower growth initially, but to attain greater age and size. In general, it appears that the differences observed between ports correspond to what one would expect from appropriate, according to the model, mixtures of fish of these two growth histories.

(f) Movements as revealed by tagging : The recovery of tags put out in southern California, central California and the northwest Pacific in all of these areas, and the recovery of tags put out in Baja California mostly in southern California and also in central California, are consistent with the differential movements suggested in the model. (This implies that no southern Baja California fish were tagged and that no central Baja California fish were tagged while those fish were in the southern California area. The tagging experiments were planned to reveal the gross features of movements and also population characteristics. A more complete analysis of the data with respect to details of movements would undoubtedly be rewarding).

(g) Spawning areas : As already indicated, the southern Baja California and Gulf of California spawning areas have been omitted from the model, and it was postulated that the catch consisted of fish produced in the southern California and central Baja California spawning areas. The question of whether or not the fish spawning in these two areas represent genetically distinct subpopulations cannot now be answered. Until very recently, it might have been concluded that the two spawning groups were not distinct. For example, Ahlstrom (1954a, 1959) has shown that in 1952 and 1953 the offshore spawning was, for all practical purposes, concentrated in the central Baja California area. In other years, the two areas have merged (or, possibly, overlapped in space, but not in time). Furthermore, Dr. Lucian Sprague had observed no differences in two blood group systems between samples from several localities. However, he has recently informed me that additional samples have revealed the existence of two genetically distinct subpopulations. Whether these subpopulations represent in fact the fish spawning on the southern California and central Baja California spawning grounds is not yet known.

Such knowledge must await the critical test of determining the blood group systen characteristics of samples drawn from spawning aggregations in the two areas.

(h) Year class size : The absolute and, especially, relative differences in year cla size between areas can be explained by varying success of spawning in the two ar plus the differential migrations already described.

Thus, it may be said that the model proposed is consonant with these eight major feat ures of the fishery and the population. These features support the model but do not, of cou verify it. On the other hand they do not, through contradiction, force abandonment of the model.

Given, then, a model that conforms reasonably well with observation, what processes can be suggested that provide a logical mechanism for the model? A major premise of the model is that spawning on the southern California spawning grounds has, for practical purpo been unsuccessful subsequent to about 1943. There are three possible explanations of this postulated lack of spawning success : (i) during the period there was no spawning in this are (ii) the spawning population was too small to produce a successful year class; (iii) some env onmental change, as yet unspecified, occurred which prevented the production of successful y classes.

What is the evidence with regard to spawning in the southern California area? Prior 1943 it is known that there was spawning in this area in 1940 and 1941 (Sette and Ahlstrom, 1 Ahlstrom, 1948), and in 1929-32 (Scofield, 1934). Unfortunately, no observations were mad from 1942 to 1948. Observations from 1949 to the present show that there was spawning in 1949 through 1951, and in 1954 through 1957. There was some spawning in 1952 and 1953, b it was so little as to be negligible. Thus, with the exception of these two years, the possibi of no spawning on the southern California spawning grounds must be rejected.

Concerning evidence as to the size of the spawning population, it is not now possible to allocate estimates of the total population between the several spawning areas for years prior 1950. However, in view of the population estimates that have been made and in view of the outstanding size of the 1939 class, it is obvious that, during the early part of the period, at least, there was a large population of spawning fish on the southern California grounds. As late as 1956 it is estimated that there were about 1.8×10^9 fish spawning in this area (Calif ornia Marine Research Committee, 1958). In view of (a) the fact that, in general, year cla sizes of pelagic marine fishes seem to vary independently of spawning stock sizes; (b) the apparent lack of dependence of sardine year class sizes on spawning stock sizes (Clark and Marr, 1955), and (c) the observation that there have been large numbers of sardines spawnin in this area in some years since 1943, I reject the possibility that the population was too small to produce a successful year class.

If the first two possibilities may indeed be rejected, there remains only the possibility that some environmental change has acted in such a way as to greatly reduce the survival rate of sardine eggs and larvae.

Before considering what this environmental change might be, I should emphasize that I do not propose to use what might be termed the "shotgun-correlation approach", i.e. the comparison of year class size with a succession of environmental variables until, sooner or later, a "significant" correlation is found, which is then assumed to represent a cause and effect relationship. It seems to me that, in order to avoid the well known pitfall, this approach must be modified to a considerable extent by logic. However, an association may be discovered, there are two remaining requirements before cause and effect can be claimed. First, there must be some logical process connecting the two variables. Second, a change in the independent variable must produce the expected change in the dependent variable. Thus, while it may be possible to explain satisfactorily historical events, in a predictive sense the second requirement can be met only with the passage of time in situations not subject to experimental control.

What has happened in the environment since 1943 that is different from the preceding period? When the CCOFI first started observations, it was noticed that spring temperatures were lower and that spawning off southern California was later in the year as compared with 1940 and 1941. This condition of below average temperatures in the mixed layer off southern California persisted for several years and did not ameliorate until late 1956 or early 1957. Thus, there are now more data with which to show this change. Fig. 47 shows the frequency of plankton hauls containing sardine eggs at the temperatures (as observed at 10 m) at which they were taken. The solid line represents the data for 1940 and 1941 off southern California (see Sette and Ahlstrom, 1948, for station pattern). The dotted line represents the data off southern California (CCOFI station lines 80-107) over the period 1950-55. The dashed line represents the data from south of Ensenada, Baja California (CCOFI station lines 110-137) over the period 1950-55. It is obvious that spawning now occurs off central Baja California at the same temperatures at which it occurred off southern California in 1940 and 1941. Furthermore, the recent spawning temperatures off southern California are 1°C lower than they were in the earlier period. Although not shown in Fig. 47, spawning commenced earlier in the year in the warmer period, and later in the year in the recent, cooler period. In 1940 and 1941, for example, the peak spawning month off southern California was April. During the recent, colder period, peak spawning months have been May or even June. During the same period, peak spawning months off central Baja California have been March and April. Cooling, if there was any, in the area off central Baja California was probably not sufficient to effect the time of sardine spawning, since the temperatures there are always greater than the apparent sardine spawning threshold temperature (about 13°C). 32/

32/ Tibby (1937) has presented data on the frequency distribution of plankton hauls containing sardine eggs at the temperatures at which they were taken for the years 1929-32 and 1936 combined. The number of hauls upon which his figure (Fig. 12) is based is much smaller than those represented in my Fig. 46. The main feature of his figure, greatest frequency at about 16°C off southern California and Baja California, corresponds in general to the curves for southern California, 1940-41, and

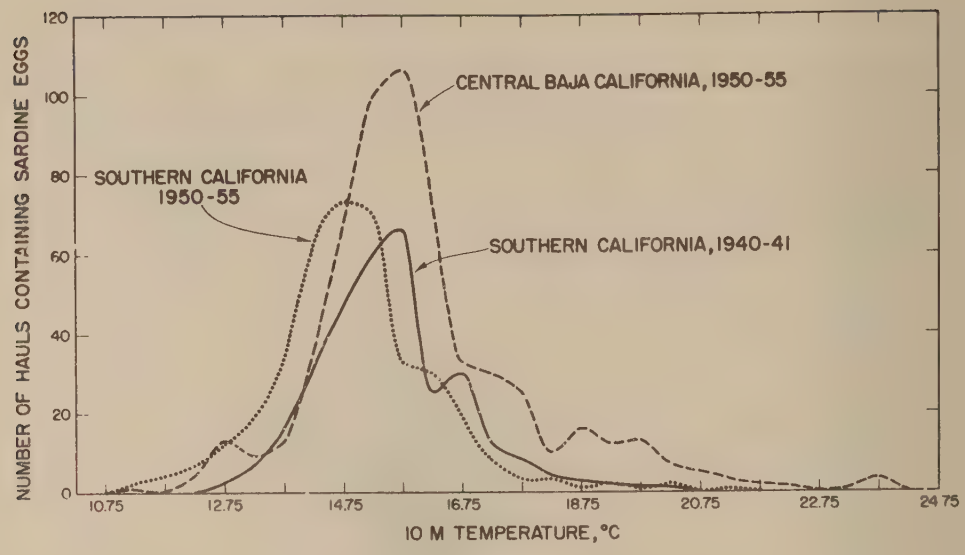

Fig. 47 Frequency distribution of plankton hauls containing sardine eggs at the temperatures at which they were taken for the area off southern California in 1940-41 and 1950-55, and the area off central Baja California in 1950-55. Data from E. H. Ahlstrom, U. S. Bureau of Commercial Fisheries.

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central Baja California, 1950-55. There are two features which differ, however. First, some eggs were taken off southern California at temperatures of 21°-24°C. These were taken in 1931 during a period of extremely high surface temperatures. Second, there is a high frequency at 14°C off southern California. This is slightly lower than the peak frequency off southern California, 1950-55. It may have been associated with a year of below average surface temperatures (1929?).

One might expect that the annual gonadal maturation cycle would be primarily controlled by (a) solar radiation, (b) quality and quantity of food, and (c) temperature. It seems likely that the first two of these factors would rarely, if ever, be limiting and that temperature is the factor most likely to be limiting, and only to the extent of delaying gonadal maturation, rather than completely inhibiting it. Gonadal maturation would be influenced, of course, by the sum of the temperature experienced between one spawning period and the next. A measure such as degree-days during a year would be appropriate. The annual sum of monthly means (of daily temperatures) is proportional to the degree-days in a year and may be used as an index of degree-days.

Unfortunately, temperature records of the waters inhabited by the sardine are not available over a long period of years. There are, however, detailed time series from coastal stations such as Scripps Pier at La Jolla, California. How reliable are such coastal records in reflecting offshore conditions? A comparison of Scripps Pier data with offshore data is possible. The Scripps Pier data have been made available through the courtesy of Mrs. Margaret Robinson, Scripps Institution of Oceanography. (For most of these data, see U.S. Coast and Geodetic Survey, 1956). Surface temperature data for the area off southern California are available from 1917 through 1938 (Imperial Marine Observatory, Kobe, 1925 et seq.). The latter data pertain to the following areas: 31-35°N, 115-119°W through 1925; 31-36°N, 115-120°W in 1926, and 30-35°N, 115-120°W from 1927 through 1938. At the coastal station and in the offshore area, the monthly mean surface temperatures were summed from April of one year through March of the following year (to correspond to the spawning cycle). Data from both series are available from 1917-18 through 1937-38. These are illustrated in Fig. 48. It is apparent that the offshore conditions are reflected at the shore station. In fact, only three years (1917-18, 1919-20, and 1920-21) depart from an exceedingly close association. Furthermore, trends in the Scripps Pier data follow in general trends in data from more northern localities (U.S. Coast and Geodetic Survey, 1956).

It is a truism to state that the interaction of sardine population and environment through recent geological time has been such that spawning which is successful is appropriately located in space and time with respect to food, predation, competition and the physical conditions in the environment. It is precisely this fine balance that would be disturbed by a prolongation of the gonadal maturation cycle and, hence, the time of spawning. One might expect, then, that a delay in spawning time would prevent successful spawning. Spawning at the "normal" time would allow the production of an outstanding year class, but would not necessarily lead to an outstanding year class; it is a condition, but not a guarantee.

In other words, I am suggesting that when the annual cumulative temperature is greater than some threshold value, sardine spawning off southern California occurs at such a time that it can be successful, other conditions permitting. It may also be unsuccessful if the other conditions are unfavorable. However, if the annual cumulative temperature is below the threshold value, spawning off southern California is delayed, is thus out of phase with its normal environment, and cannot be successful. The kind of relationship postulated is analogous to that suggested by Rae (1957) between wind and haddock year class size.

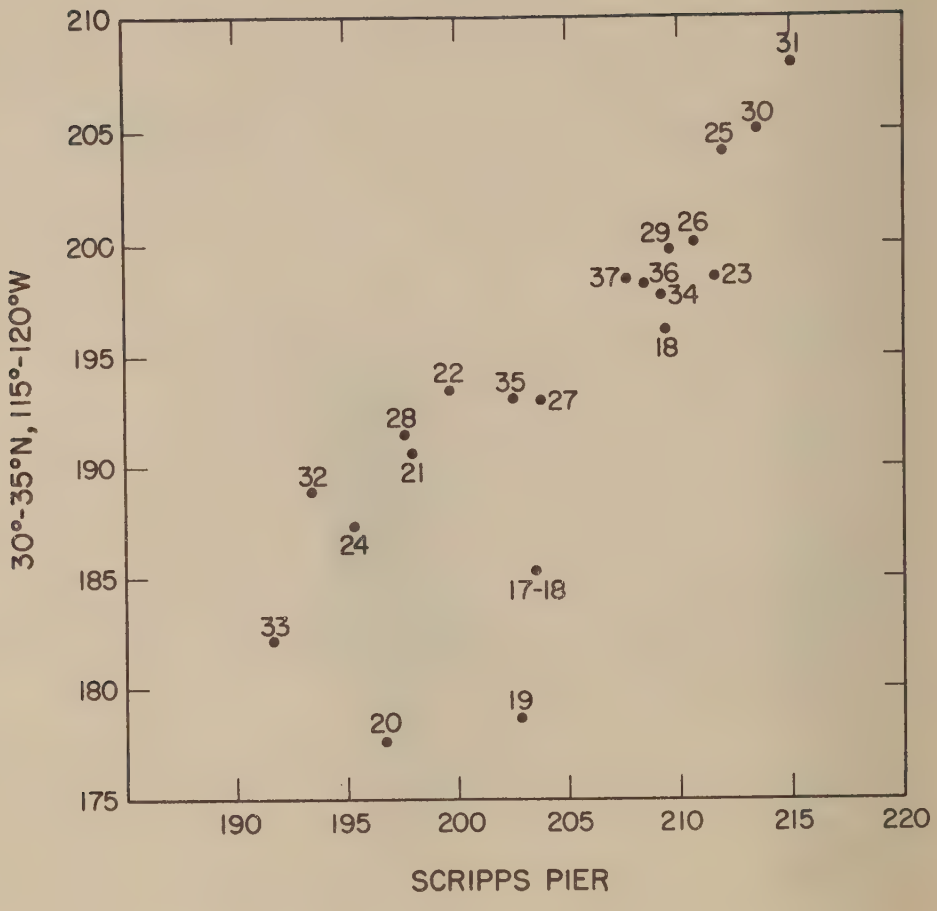

Fig. 48 Relationship between surface temperature at Scripps Pier and the adjacent 5° square, April through March. Data from U.S. Coast and Geodetic Survey (1956) and Imperial Marine Observatory, Kobe (1925 et seq.). See text (5.4) for further explanation.

If year class size is plotted as a function of annual cumulative temperature, the field may be divided horizontally by a line passing through the mean year class size and vertically by a line passing through the threshold temperature value. Outstanding year classes (those greater than mean year class size) should all be found in the upper right quadrant, smaller than average year classes will be found in both the lower right and lower left quadrants, and none should be found in the upper left quadrant.

Sardine data, with one notable exception, conform to expectation, as shown in Fig. 49 where year class size is plotted as a function of a measure of annual cumulative temperature at Scripps Pier. Mean year class size is slightly in excess of 2×10^9 fish and is indicated by the horizontal line. The threshold temperature appears to be at about 201 units and is indicated by the vertical line. The 1941, 1943, 1946 and 1948 classes probably do not differ significantly from the mean and may be ignored here. The 1936, 1937, 1938, 1940, 1942 and 1947 are all outstanding classes, and fall in the upper right quadrant. The 1935 and 1944 classes fall in the lower right quadrant. Presumably, some environmental factor other than temperature restricted the size of these year classes. The 1934, 1945, 1949 and 1950 through 1955 classes are all in the lower left quadrant and, according to the model, were limited by temperature conditions. It should, however, be kept in mind that, while I am here considering the success of spawning off southern California, the measure of spawning success used (i.e. accumulated age estimates of year class size) is based on all fish entering the catch, regardless of the area in which they were produced. It was necessary to use this measure because of the nature of the data. Some inexactitude may thus have been introduced.

The single exception mentioned above is the 1939 class, which lies in the upper left quadrant. Does the location of this point indicate that the postulated relationship between year class size and temperature is not realistic, or that the 1939 class represents an exception to a relationship that generally obtains? I am inclined to the latter alternative, primarily because 1939 was an anomalous year in at least two respects. First, surface temperatures during the first half of the year were below average, whereas during the last half of the year they were considerably above average. Second, sardine spawning and spawning success was distributed more to the north, off the coasts of Washington and Oregon, than has been observed in any other year. (As a result of northern spawning success, the 1939 class may have been more available to the fishery than were other year classes. If this is true, the estimate of the size of the 1939 class is too large relative to the estimates for other classes.) Beyond speculation, I cannot offer an explanation of why these anomalous conditions should result in a large year class.

Returning to the apparent general relationship between cumulative temperature and year class size, I have already suggested that when the annual cumulative temperature is below the threshold value, sardine spawning off southern California is delayed, the eggs and larvae are out of phase with their normal environment, and successful spawning is thus precluded. Specifically, I wish to propose that the delay in sardine spawning places the sardine larvae at a disadvantage with respect to the northern anchovy, a major competitor.

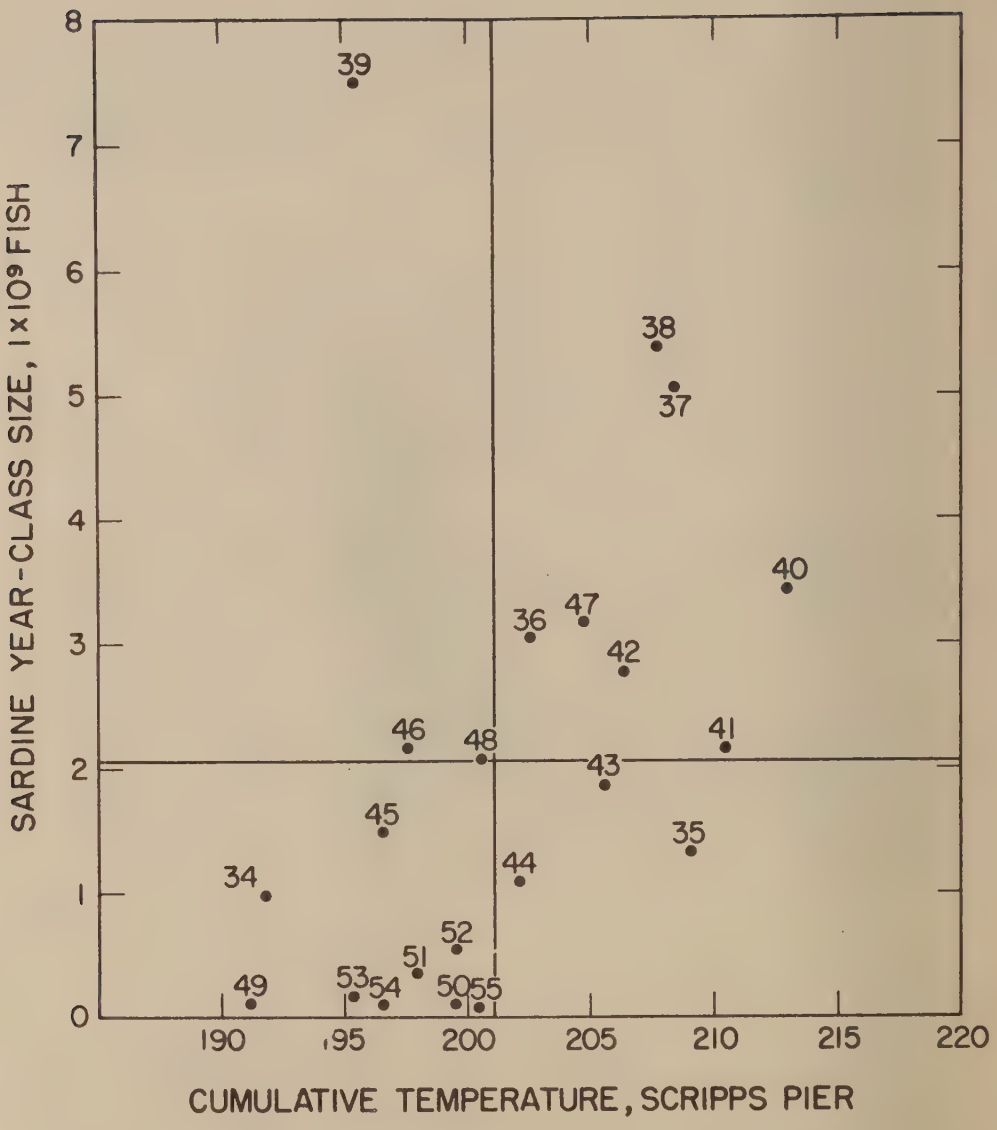

Fig. 49 Relationship between sardine year class size and a measure of annual cumulative temperature (sums of monthly means, April through March) at Scripps Pier. Data are from Table XIV, U.S. Coast and Geodetic Survey (1956), and Mrs. M. Robinson, Scripps Institution of Oceanography.

The evidence for such a relationship, while circumstantial, is very suggestive. It includes (a) the distribution of larvae, (b) the food items of larvae, (c) threshold spawning temperatures, and (d) abundance. 33/

The distribution of anchovy larvae has been well documented (Ahlstrom, 1952, 1953, 1954b, 1956, 1958; Ahlstrom and Kramer, 1955, 1956, 1957; California Marine Research Committee, 1952, 1953 and 1958). In brief, the distribution of anchovy larvae tends to correspond with the distribution of sardine larvae. However, anchovy larvae occur less far offshore than the sardine larvae. They are present over a longer period than are sardine larvae. Thus, the distribution of anchovy larvae in terms of the location of sardine larvae is extensive but incomplete in space, complete in time. The physical opportunity for competition exists.

Studies of the food of anchovy and sardine larvae (Arthur, 1956; California Marine Research Committee, 1953) have shown them to have very similar food habits. Over half the items observed in the stomachs of the larvae of both species were copepod nauplii. Further, the size range of food items ingested by both species is very similar, the range for the anchovy being slightly greater. The physical opportunity for competition for food between anchovy and sardine larvae is thus realized.

The threshold temperature for sardine spawning is about 13°C. The threshold temperature for anchovy spawning is about 11°C with a peak at about 14°C (Ahlstrom, 1956). Both the threshold and peak spawning temperatures for the anchovy are about 2°C lower than the corresponding temperatures for the sardine. It seems logical, then, that years of lower temperatures would tend to favor the anchovy over the sardine.

There is, in fact, evidence that during the cold period which ended late 1956 or early 1957, the abundance of anchovy larvae off southern California increased as compared to abundance in 1941, a warm year. The following data on the relative abundance of anchovy larvae off southern California have been supplied by Dr. E. H. Ahlstrom, U.S. Bureau of Commercial Fisheries :

33/ There are, of course, larvae of several other species of fishes commonly found in the CCOFI area. Together with sardine and anchovy larvae, the larvae of the hake (Merluccius productus), rockfishes (Sebastodes spp.), jack mackerel and Pacific mackerel account for about three-quarters of all the larvae taken. The remainder is made up of fewer individuals of a great many species (Ahlstrom, 1958). Although the larvae of some of the species listed are exceedingly abundant, they have not been considered as competitors of sardine larvae either because of lack of knowledge (about food habits, for example) or because they do not meet the four requirements listed. Jack mackerel larvae, for example, are found more offshore and more to the north than are sardine larvae (Farris, 1958, in press), and eat larger and different food items (California Marine Research Committee, 1953).

Year	Average number/haul
1941	50
1953	86
1954	164
1955	120
1956	71
1957	310

The large increase in abundance in 1957 was associated with a decrease off Baja California; both were undoubtedly associated with a general ecological northward shift as the result of increased temperature. The abundance in each of the cold years, 1953-56, was greater than that observed in 1941; on the average it was somewhat over twice as great.

Doubt has been expressed as to the existence of interspecific competition between fish larvae, owing to the fact that fish larvae are such a minor constituent of the plankton community. This is not necessarily a valid objection since, in this sense, the fish larvae must not be considered as members of the entire plankton community, but only as members of that fraction of the total community which is made up of food items and competitors for those items. Thus, in an operational sense, fish larvae may be important constituents of the plankton, particularly in areas of high larval abundance. Definitive data with which to resolve this problem are not now at hand, but collections to provide such data should not be difficult to design.

In this same connection, it has been suggested that, rather than interspecific competition between the sardine and anchovy larvae, the dominance of one species or the other would be favored by water masses of differing origin, and their associated distinctive faunas. For example, survival of anchovy larvae would be favored by water with a more northern fauna and survival of sardine larvae by water with a more southern fauna. This concept is not necessarily in conflict with my hypothesis of interspecific competition, since competition is one of the two major ways in which a different fauna would "favor dominance" of one species or the other. Furthermore, if a water mass with a more southern fauna does favor (without specifying how) the survival of sardine larvae over anchovy larvae, the influence of the temperature regime on the gonadal maturation cycle (suggested above) provides a mechanism through which genetic selection could operate to locate spawning at the appropriate time and place. In the presentation of my model I did not consider the implications of temperature changes with respect to oceanographic features. A brief discussion of this is included below.

It is now pertinent to consider the model developed here, together with those presented by Walford (1946) and Sette (1960). These models are all concerned with different facets of the same complexity in nature, and it appears to be possible to reconcile them.

The positive association between year class size and salinity at Scripps Pier observed by Walford in an earlier period was found to be reversed in a later period. I have mentioned that variations in salinity at Scripps Pier may arise from several causes, and that salinity does not vary simply as a function of the amount of upwelling. Low salinity may result from run-

off (as was probably the case in 1941) or from an increase in the speed of the California Current (the result of intensification of meteorological and oceanic circulation in the North Pacific Ocean). However, intensification of the California Current is also associated with increased northwesterly winds, increased upwelling and evaporation and, thus, an increase in salinity. A reduction in the California Current might result in a slight increase in salinity through insolation and evaporation, but upwelling would probably suffer a concomitant reduction and the action of upwelling in increasing salinity would be accordingly reduced. Finally, salinity may be increased as the result of advection of offshore or southern water (as was probably the case in 1939). It is probable that the two major causes of high salinity at Scripps Pier are increased upwelling and advection of offshore or southern water. It is likely that the processes leading to these two situations are mutually exclusive; i.e. high salinity may result from one cause or the other, but not both simultaneously.

Obviously, high salinity at Scripps Pier would give no indication of which of two quite different regimes actually existed in the ocean. Temperature will assist in making the distinction. All of the changes in salinity discussed above (ignoring run-off for the moment), except one, are associated with parallel changes in temperature. The one exception is the increase in salinity from upwelling, which is associated with a decrease in temperature. The changes in salinity and temperatures from the different causes may be summarized as follows :

Variable	Change in Temperature	Salinity
1. Increased run-off	?	decrease
2. Intensification of California Current	decrease	decrease
3. Increased upwelling (probably associated with 2. above)	decrease	increase
4. Reduction of California Current	increase	increase (slight)
5. Advection of offshore or southern water	increase	increase

Consideration of these temperature-salinity relationships in connection with the cumulative temperature - year class size relationship postulated above (Fig. 49), suggests that the threshold cumulative temperature (postulated as a requisite for successful year class production off southern California) occurs in years of an advection regime rather than an upwelling regime.

Thus, the reversal of the salinity - year class size relationship in Walford's model and the general features of my model are not inconsistent. In fact, they may be regarded as supplementing each other, provided that there is evidence for a change from an advection regime to an upwelling regime.

Is there such evidence? As has already been indicated, above average upwelling is associated with above average northwesterly winds (Sverdrup et al, 1942; Reid et al, 1958; Roden, 1958) and, conversely, the advection of offshore or southern water is associated with below average northwesterly winds (Sverdrup et al, 1942; Reid et al, 1958). Data on the relative strength of northwesterly winds, and thus by inference, on the relative dominance of the upwelling or advection regimes, have been given by Reid et al. (1958), Roden (1958), and Sette (1960). These data show that the northwesterly winds were below average during an earlier period and above average during a later period. The period of below average winds corresponds in general to the period in which Walford observed a positive correlation between salinity at Scripps Pier and year class size and to the period in which I believe the production of successful year classes off southern California occurred. Similarly, the period of above average winds corresponds in general to the period in which there was a negative correlation between salinity at Scripps Pier and year class size, and the period in which I believe the production of successful year classes off southern California was not possible.

Additional evidence may be found in the temperature and salinity data taken at Scripps Pier. These may be seen in Fig. 50, in which the sums of the monthly means of temperature from April through March are plotted against the analogous values of salinity. The 1934 through 1943 data are plotted as open circles; the 1944 through 1955 data are solid squares. The common means of temperature and salinity for the two periods are indicated by plus signs; they are obviously different. Furthermore, the points for the two periods tend to form discrete arrays. Only the point for 1938 lies within the array of the more recent period. None of the points of the more recent period lie within the array of the earlier period. It may be seen that on the average higher temperatures and lower salinities characterized the earlier period, whereas lower temperatures and higher salinities characterized the more recent period. In addition, the range of temperature and salinity was much less in the recent period than in the earlier period.

The advection of offshore or southern water into the region off southern California may simply be a consequence of the weakening of the California Current, rather than an intensification of the southern California eddy as postulated by Sette (1960). While this may constitute a sematic rather than an oceanographic problem, it is pertinent to point out that there are really two phenomena involved, between which there may be some confusion. First, owing to the configuration of the coastline and the direction of the California Current, a counter-clockwise eddy south of Point Conception is to be expected. However, this eddy should be intensified under conditions of above average northwesterly winds and weakened under conditions of below average northwesterly winds. In addition to this eddy, there exists a counter-current between the California Current and the continental land mass. During periods of strong northwesterly winds this is a subsurface current. It becomes a surface current during periods of reduced northwesterly winds. When it is a surface current in the area off southern California, it might be regarded as part of the eddy. But this is somewhat inexact, since the counter-current may continue northward along the coast north of Point Conception. This condition

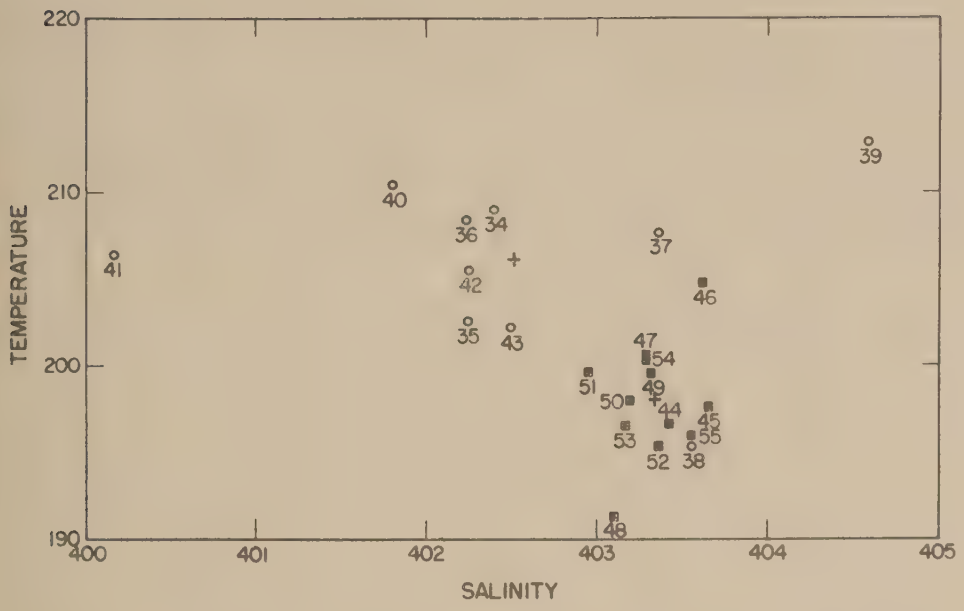

Fig. 50 **Relationship of the sums of the monthly means, April through March, of temperature and salinity at Scripps Pier, 1934 through 1955. Data are from U.S. Coast and Geodetic Survey (1956, 1958) and Mrs. M. Robinson, Scripps Institution of Oceanography.**

obtained, in fact, in 1958 when drift bottles released at inshore stations off southern California were carried greater distances north of Point Conception and at greater speeds than had been observed in immediately prior years (Reid, 1960). In this same year, it will be recalled, drift bottles released farther offshore yielded no greater returns than those released in years of above average northwesterly winds and below average surface temperatures (Fig. 46).

In any case, it does appear that the three apparently different models are not in broad fact different, but that they tend to reinforce and buttress the conclusion that a major change in the oceanographic regime has occurred off southern California, and that this change has coincided in time with a change in sardine year class size. The details of my model are based on a summary of the knowledge of sardine biology, of the fishery, and of the environment, and

suggest a specific mechanism through which the environment may act to produce variations in year class size.

The model proposed, therefore, which is in accord with the history of the fishery and the biology of the species, and which offers an explanation of the decline in the fishery, may be iterated and completed as follows :

(a) sardines produced on the spawning grounds off southern California and central Baja California make up the bulk, or all, of the United States and Canadian catch;

(b) sardines produced on the southern California spawning grounds migrate as far north as British Columbia, support the fishery there and contribute to the fisheries at San Francisco, Monterey and San Pedro;

(c) sardines produced on the central Baja California spawning grounds migrate as far north as central California and contribute to the fisheries at San Francisco, Monterey and, especially, San Pedro;

(d) lack of spawning success on the southern California spawning grounds since about 1943 could thus account for the observed changes in the fishery;

(e) lack of spawning success on the southern California spawning grounds has not resulted from lack of spawning, but rather from a below average temperature regime that has acted to delay spawning and place the eggs and larvae out of phase with their normal environment;

(f) it is proposed that the interaction between sardine larvae and their environment, under the temperature imposed delay, is mediated through competition with anchovy larvae, which species has a lower temperature threshold;

(g) the temperature regime is determined by oceanographic conditions, such that low temperatures (and high salinities) occur under conditions of above average northwest winds, and high temperatures (and high salinities) occur under conditions of below average northwest winds. Apparent differences between my model and those proposed by Walford and Sette may thus be resolved.

If fishery biology is to advance beyond the purely descriptive stage, knowledge accumulated through the necessary and frequently tedious descriptive studies must be gathered together and related in terms of dynamic processes. The model presented here is an attempt to accomplish this objective for one species. While my model does relate present knowledge of the Pacific sardine in what seems to me to be a logical manner, it is obvious that the evidence is not always as clear cut as one might desire. The judgments made in the course of constructing the model were, perforce, sometimes made on the basis of the most likely alternative among several, rather than on the basis of a simple choice between opposing alternatives. The model must, therefore, be regarded as only a first approximation. It is my hope that it is realistic enough to both warrant and inspire critical testing in the laboratory and at sea.

SUMMARY

(a) The historical record of the sardine fishery and sardine biology are reviewed as a requisite to developing a model that is not only consonant with the record, but offers an explanation of it;

(b) the curve of total landings from the inception of the fishery in about 1916, through the 1944-45 season, can be described by a logistic with an asymptote of about 600,000 tons. Following this there was a series of declines and resurgences. Total landings were practically zero in two seasons, but reached about 100,000 tons in the 1958-59 season;

(c) although the initial decline appeared first and most severely in the Pacific Northwest and progressed to the south, the post 1944-45 history of the fishery in the four areas considered (British Columbia, San Francisco, Monterey, and San Pedro) was not identical. The fishery has been most persistent at San Pedro;

(d) catch per unit-of-effort at the three California ports was similar in the early 1930's, but differed subsequently. Catch and catch per unit-of-effort tend to be positively associated at San Pedro and Monterey, but not at San Francisco;

(e) derived estimates of effort at the three California ports are dissimilar. Effort at San Francisco rose to a peak, declined, and rose again. Effort at Monterey tended to rise gradually and then declined somewhat. It dropped to zero at both ports. Effort at San Pedro tended to rise gradually and in later seasons to show changes (perhaps unrealistic) as great as 100 per cent between adjacent seasons;

(f) several aspects of age data are considered. Average age tends to be high in early and late periods, especially at Monterey and San Pedro. Changes in average age may be attributed to variations in year class strength, availability and, to some extent at Monterey and San Pedro, changes in effort. The dominant age in the catch tends to decrease from north to south and only at San Pedro was a single age, two, outstandingly dominant. The number of year classes in the catch tends to increase from south to north, but only slightly. The age at full recruitment tends to increase from south to north. However, recruitment at age one is more common at Monterey than San Pedro. Age two is dominant at San Pedro; age three at Monterey. Average percentage contributions by ages tend to be similar at the California ports, with age two dominant. Age four is dominant in British Columbia;

(g) several aspects of length data are considered. Average length curves resemble age curves. Average age and average length show a close positive association. This association is similar for the California ports; the regression for British Columbia has large slope and intercept (negative) values. Average length at the end of the first year of life is essentially the same for earlier year classes in all areas. Following the 1943 class it increased greatly. The possibility exists that this is a density dependent change, but probable differences in the available food

supply suggest that it is density independent. Length-on-age curves suggest a slower-growing, longer-lived type from British Columbia and a faster-growing, shorter-lived type at San Pedro. Average growth curves of fish taken at the California ports appear to reflect varying mixtures of these two types. Growth by seasons, adjusted for age of fish, shows great similarity between the four areas;

(h) for a given length, fish tend to be heavier at Monterey than at San Pedro. Fish from British Columbia are heavier than those from San Pedro only at the longest lengths. Condition factor tends to be negatively associated with population size;

(i) published evidence on availability is briefly reviewed. Of particular importance is the evidence from tagging. Fish tagged in one area tended to be recovered in all others, except that of the fish tagged off Baja California about 75 per cent were recovered in southern California and 25 per cent in central California;

(j) there are four sardine spawning areas : off southern California, off central Baja California, along southern Baja California, and in the Gulf of California;

(k) the annual rate of fishing mortality has been very low since 1950. The annual rate of natural mortality may have been rather high;

(l) accumulated age estimates, by ports, of year class sizes show that their relative abundance varied with area. The 1939 class, for example, was relatively more abundant in the north, while the 1948 class was relatively more abundant in the south;

(m) accumulated age estimates, by ports, of population size show similar differences, owing to the influence of geographic variation in relative year class abundance;

(n) the general effects of a fishery upon a population are briefly and simply reviewed;

(o) available data on the yield per recruit relationship of the sardine indicate that the fishery has, in general, been operating in such a way as to take advantage of this relationship. In this respect, the yield could not be maximized by changing the age (size) at first capture or the fishing mortality;

(p) additional data now available show that Schaefer's model does not describe the sardine population. Contrary to his model, the major changes in population size appear to be density-independent;

(q) there does not appear to be a relationship between sardine spawning stock size and year class size;

(r) additional data now available show that Walford's model relating to salinity (as a measure of upwelling) and year class size does not obtain;

(s) Sette's model, which states that when northwesterly winds are below average, surface temperatures are higher, the southern California eddy is better developed and survival of sardine larvae is greater, does not appear to provide a complete explanation for major levels of variation observed in sardine year class sizes. There are no consistent differences in drift bottle recoveries and, by implication, eddy development, between years of above average northwesterlies and below average surface temperatures and years of below average northwesterlies and above average surface temperatures;

(t) a model, consonant with the record, which offers an explanation of the decline, is : sardines which support the United States and Canadian catch are produced off southern California and central Baja California. Those produced off southern California migrate as far north as British Columbia, support the fishery there and contribute to the fisheries at San Francisco, Monterey and San Pedro. Those produced off central Baja California migrate as far north as central California and contribute to the California fisheries, especially San Pedro. Lack of spawning success on the southern California spawning grounds since about 1943 could account for the observed changes in the fishery;

(u) the lack of spawning success off southern California is attributed to environmental conditions; specifically, the below average temperature regime which has delayed sardine spawning off southern California by one or two months. It is proposed that, under these conditions, sardine larvae are unable to compete successfully with the anchovy, which has a lower temperature threshold. Below average temperatures are associated with an upwelling regime and above average temperatures with an advection regime. Thus, the models of Walford and Sette are not in conflict with the one proposed here.

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DISTRIBUTION OF CATCH-PER-UNIT-OF-EFFORT AND FISHING EFFORT FOR TUNA IN THE EASTERN TROPICAL PACIFIC OCEAN BY MONTHS OF THE YEAR, 1951-1960

by

John Wilson Martin[1]

INTRODUCTION

The Inter-American Tropical Tuna Commission has systematically collected catch and effort data from logbooks of baitboats and purse-seiners fishing for yellowfin *(Neothunnus macropterus)* and skipjack *(Katsuwonus pelamis)* tuna in the Eastern Tropical Pacific Ocean since 1951, the primary purpose being to monitor changes in fishing effort, abundance and yield for these species. Detailed descriptions of the methods of collection, tabulation and analyses of these data are given by Schaefer (1953), Shimada and Schaefer (1956) and Shimada (1958). Much of the basic data has been published in the Commission *Bulletin* series by Shimada and Schaefer (1956), Alverson (1959 and 1960), Griffiths (1960), and Calkins (1961).

Comparison of physical and biological environmental factors affecting the aggregation of tunas with the success of fishing by the commercial fleets, requires that catch and effort data be examined in greater detail than has been presented in these publications. Consequently, the United States Bureau of Commercial Fisheries Biological Laboratory, San Diego, to serve the needs of its program of research on causes of variations in tuna abundance, made arrangements with the Tuna Commission to summarize these catch and effort data by month, by one-degree area, by fishing vessel size-class, for the years 1951-1960 for baitboats and 1953-1960 for purse-seiners. The present paper describes the techniques employed in summarizing these data by automatic data processing methods. It also presents the catch and effort information by months, by five-degree areas and certain combinations of five-degree areas for use by fishermen, industry personnel, and research agencies. Because of space limitations and other considerations, the one-degree tabulations are not included but are available at the Tuna Commission and Bureau laboratories.

An International Business Machines (IBM) 650 computer system, made available to the Bureau by General Dynamics-Convair, San Diego, was used for standardizing fishing effort, for pro-rating unidentified catch and for computing apparent abundance of each species by time and area strata. The author prepared special computer instructions to facilitate the rapid handling of the basic data.

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METHODS

The basic data utilized in this report are a product of the logbook system established by the Tuna Commission in 1951, to monitor, on a current basis, the activities of the tropical tuna fishing fleets. The methods used in this system have been reported in detail by Schaefer (1953) and Shimada (1958) and are discussed here only superficially. Data respecting fishing effort and resulting catches of yellowfin and skipjack tuna are obtained from the trip records contained in the logbooks kept by the masters of baitboats and purse-seiners fishing in the Eastern Tropical Pacific Ocean.

Personnel from the Tuna Commission staff transcribe, analyse and tabulate these data on a current basis. To facilitate the handling of this large quantity of information, the tabulated data are recorded, at the end of each year, on punch cards in a format which lists area fished by one-degree rectangle, month, size-class and type of vessel, days fished and catch of yellowfin and skipjack tuna. These punch cards were loaned to the U. S. Bureau of Commercial Fisheries and provided the information necessary to prepare this report.

The Commission's statistical areas and their assigned code numbers are shown in Figure 1. The smallest divisions are one-degree areas which combine to form the larger five-degree areas. Areas north of the equator are identified in code by seven digits. An additional prefix, the digit "2", is used to denote areas south of the equator and is so shown in the tables.

The five-degree areas are designated by the latitude and longitude of their southeast corner and are sub-divided into 25 one-degree areas which are serially numbered from the southeast corner, as shown in Figure 1. Area 25-110 is divided by the peninsula of Baja California. The eastern and western portions of this five-degree area are denoted by "A" and "B", respectively, for the purse-seine data since seiners fish in both portions. No such designations are given for the baitboat material because baitboats do not normally do much fishing in the upper Gulf of California.

Standardization of Fishing Effort

The success of fishing for yellowfin and skipjack tuna is related to vessel size. Shimada and Schaefer (1956) described a method of adjusting effort to a standard vessel size-class to permit comparison of fishing success by vessels of the various size categories which operate throughout the Eastern Tropical Pacific Ocean. Six size-classes of vessels were established by them, based on fish-carrying capacity: Class 1, up to 50 tons; Class 2, 51-100 tons; Class 3, 101-200 tons; Class 4, 201-300 tons; Class 5, 301-400 tons; and Class 6, 401 tons and over. Size-classes 4 and 3 were established as the standard for baitboats and purse-seiners, respectively, and all fishing effort is then adjusted to equivalent days fishing by these classes of vessels. The yearly efficiency factors for baitboats and purse-seiners for the ten years, 1951-1960, are being published by Broadhead (1962).

For the purpose of this report, mean efficiency factors obtained from the eight-year period, 1951-1958 were used in the standardization of the fishing effort of the baitboat fleet for the years 1951-1960. The mean efficiency factors for the period 1953-1958 were used for the purse-seine vessels over the period 1953-1958. However, a new set of mean values for standardizing purse-seine data, beginning in 1959, was required by the sudden change in the composition and character of the purse-seine fleet. This was brought about by the mass conversion of baitboats to purse-seiners which is discussed by Broadhead and Marshall (1961). Since the 1959 purse-seine data were processed early in 1960, efficiency factors calculated from the 1959 data were used for that year. Average values, obtained from the 1959 and 1960 data, were used to standardize the 1960 purse-seine effort. The following table lists the sets of efficiency factors, employed for standardization of fishing effort, for the two types of gear, according to size-class.

Gear and Period	Size-classes					
	1	2	3	4	5	6
Baitboats 1951-1958	0.40	0.55	0.84	1.00	1.18	1.16
Purse-seiners 1953-1958	—	0.88	1.00	1.37	—	—
Purse-seiners 1959	0.60	0.82	1.00	1.30	1.20	—
Purse-seiners 1959-1960	0.66	0.73	1.00	1.35	1.27	1.01

Species Recorded

The catches reported in the logbooks are tabulated under four categories: yellowfin; skipjack; mixed yellowfin and skipjack; and yellowfin or skipjack, not separately identified. The computer was instructed to prorate tonnages in the latter two categories in the ratio of identified tonnage of yellowfin and skipjack reported for each one-degree area by quarters of the year. Alverson (1960) reported that the two categories of mixed or unidentified tuna together contained, for the period 1951-1958, some 9.7 per cent of the baitboat and 6.4 per cent of the purse-seine tonnage logged.

Modifications in Data

Some minor key-punch errors were detected in the original detail cards when processing the data with the IBM 650 computer. These defective cards, which were rejected by the computer, were estimated to contain less than one per cent of the data, based on comparisons among quarterly and annual totals of catch and effort compiled by the Commission and the Bureau. The use of mean efficiency factors, rather than the yearly values, for standardization of effort also resulted in minor differences between the data presented in this paper and those published by Alverson (1960). Comparison of the present machine-run tabulations from a series of areas with those of the Commission indicated that the differences are insignificant, when the data are used to examine changes in tuna availability by time and area strata.

RESULTS

Tables 1 and 2 list the standardized effort and corresponding catch-per-standard-day's-fishing (SDF) logged by baitboats and purse-seiners, for yellowfin and skipjack tuna, by five-degree area, by month and by year, for each type of gear. As noted by Griffiths (1960), data which are based on less than five days fishing should be viewed with caution, because small amounts of effort often generate unreliable measures of apparent abundance of tuna.

To examine seasonal trends in apparent abundance, the data of five-degree areas were consolidated into ten large geographical divisions of the fishery, as shown in Figure 2. These regions correspond rather closely to those employed by the Tuna Commission in their studies of age, growth, spawning, and sexual maturity of the tropical species but do not necessarily indicate natural population boundaries.

The monthly trends in catch-per-standard-day's fished are shown in Figures 3-12, utilizing only the baitboat data. Data for yellowfin are indicated by the solid lines and for skipjack by the broken lines. The amount of fishing effort used to calculate catch-per-standard-day-fished is given by the number adjacent to the point for each month and those months without effort have been left blank. Logged tonnage by species may be estimated by the product of the number of days fished and the catch (in tons)-per-standard-day-fished. The tonnage logged in an area is less than the total catch for the area, because a few of the large baitboats and purse-seiners do not keep logbook records and logbooks are not maintained aboard miscellaneous small craft fishing for the tropical tunas. Alverson (1960) notes that logbook coverage varied from a low of 61.4 per cent in 1951, when the Commission first began its logbook system, to a high of 82.1 per cent in 1958; 75.6 and 80.8 per cent coverage was obtained in 1959 and 1960, respectively. The overall average for the ten-year period was 76.6 per cent. The fact that logbook data are not obtained for 100 per cent

f the catch does not significantly affect the catch-per-standard-day-fished ecause the logbook sampling is sufficiently large and well-stratified as to ime and area.

Examination of the tables and charts demonstrates that success of una fishing in particular five-degree areas is frequently highly variable rom month to month in the same year, and among years for the same nonth. These variations are even greater for one-degree areas. Factors ffecting or controlling availability of the tropical tunas are highly com- lex. No attempt is made, at this time, to relate variations in the catch ate and the total catch to environmental and biological conditions. These asic data, however, will be useful to scientists of the Bureau of Commer- ial Fisheries, the Tuna Commission, and Scripps Institution of Oceano- raphy in such studies which are presently underway.

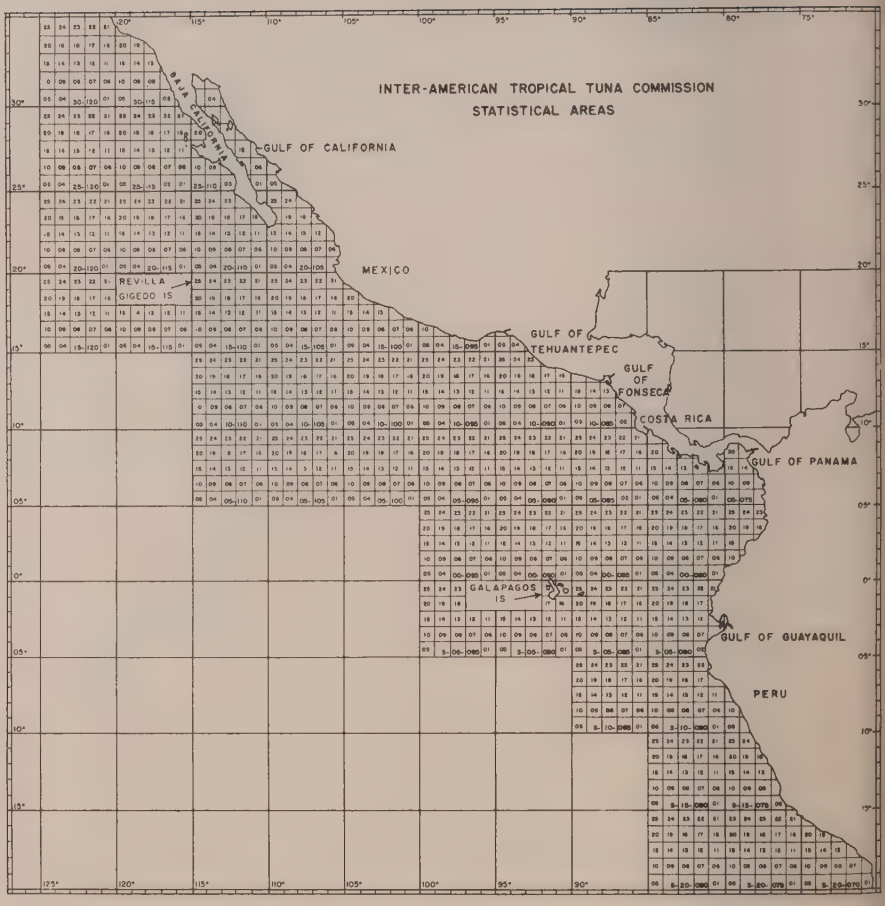


FIGURE 1. Statistical areas employed by the Inter-American Tropical Tuna Commission.

FIGURA 1. Areas estadísticas empleadas por la Comisión Interamericana del Atún Tropical.

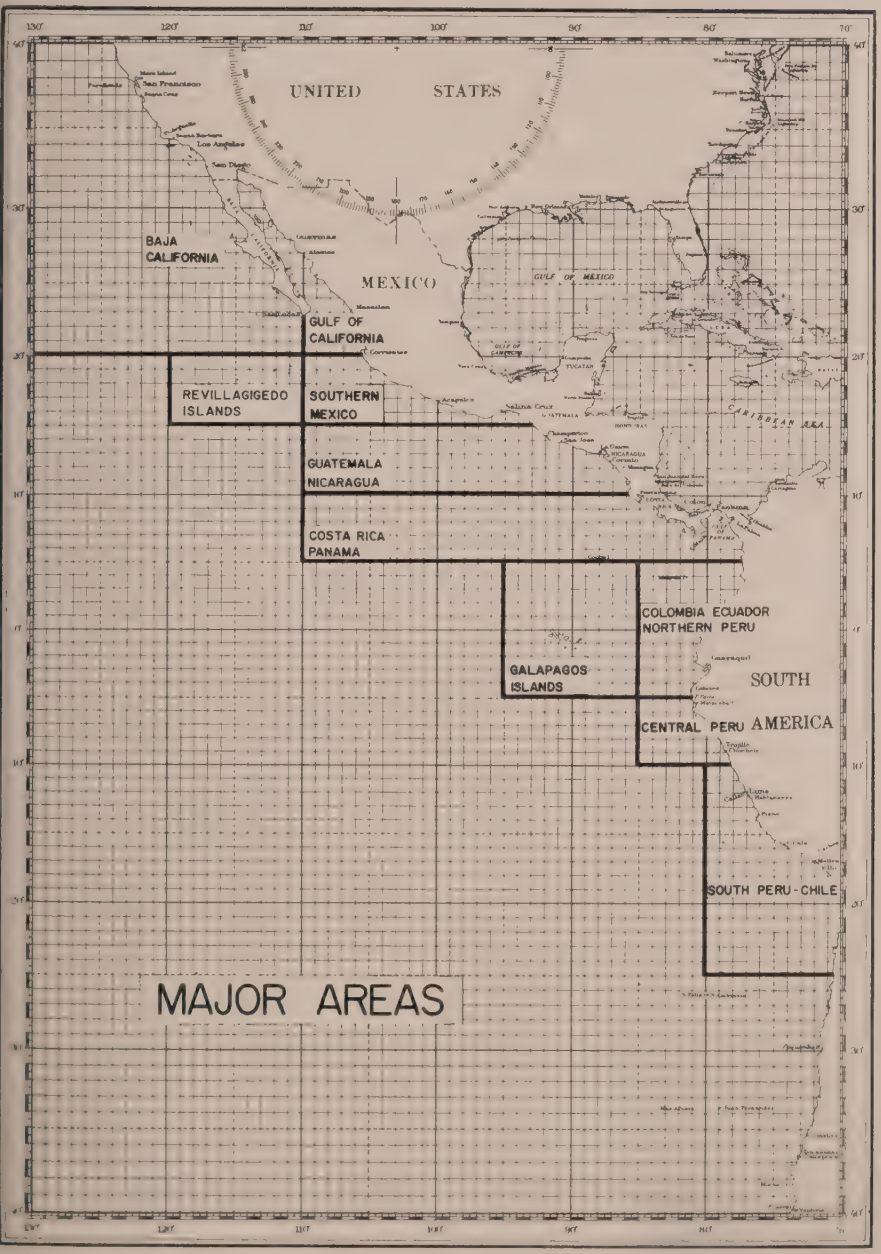


FIGURE 2. Major geographical areas of the tuna fishery.

FIGURA 2. Areas geográficas mayores de la pesquería del atún.

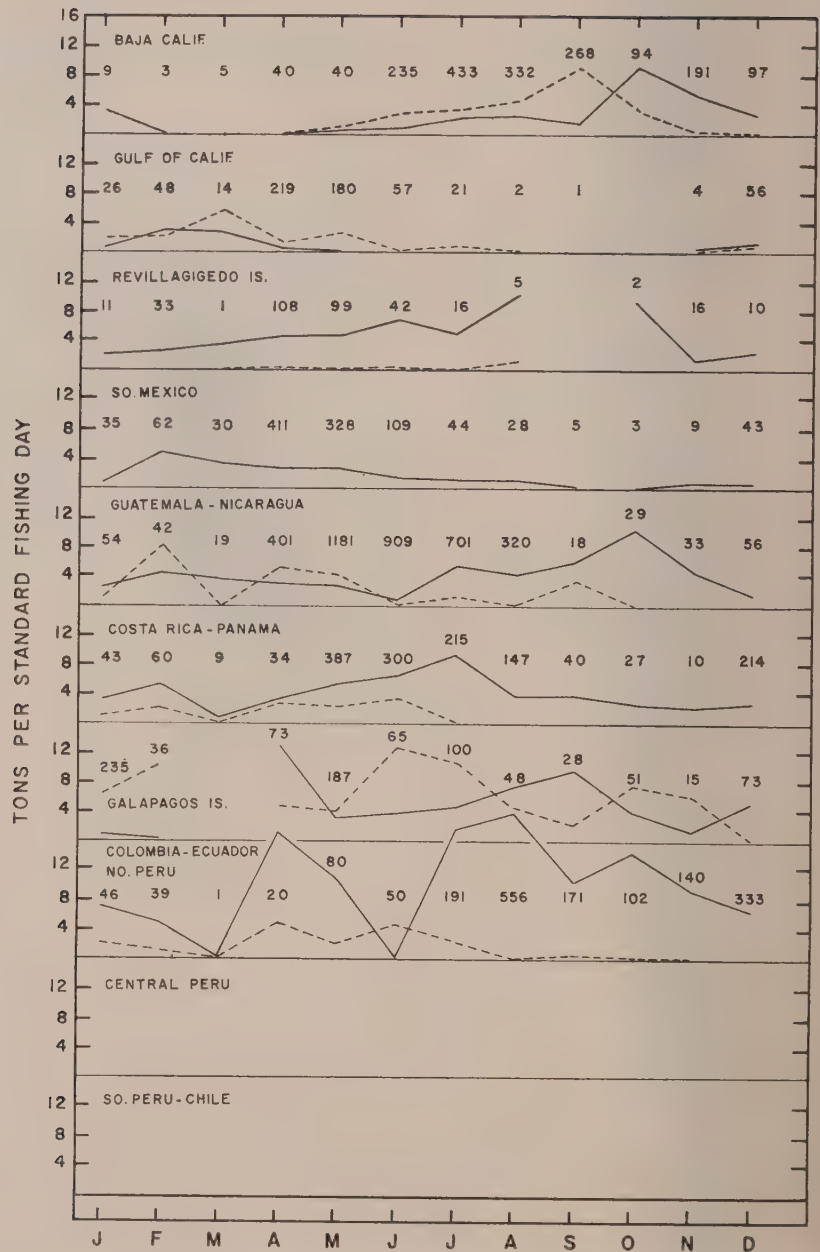
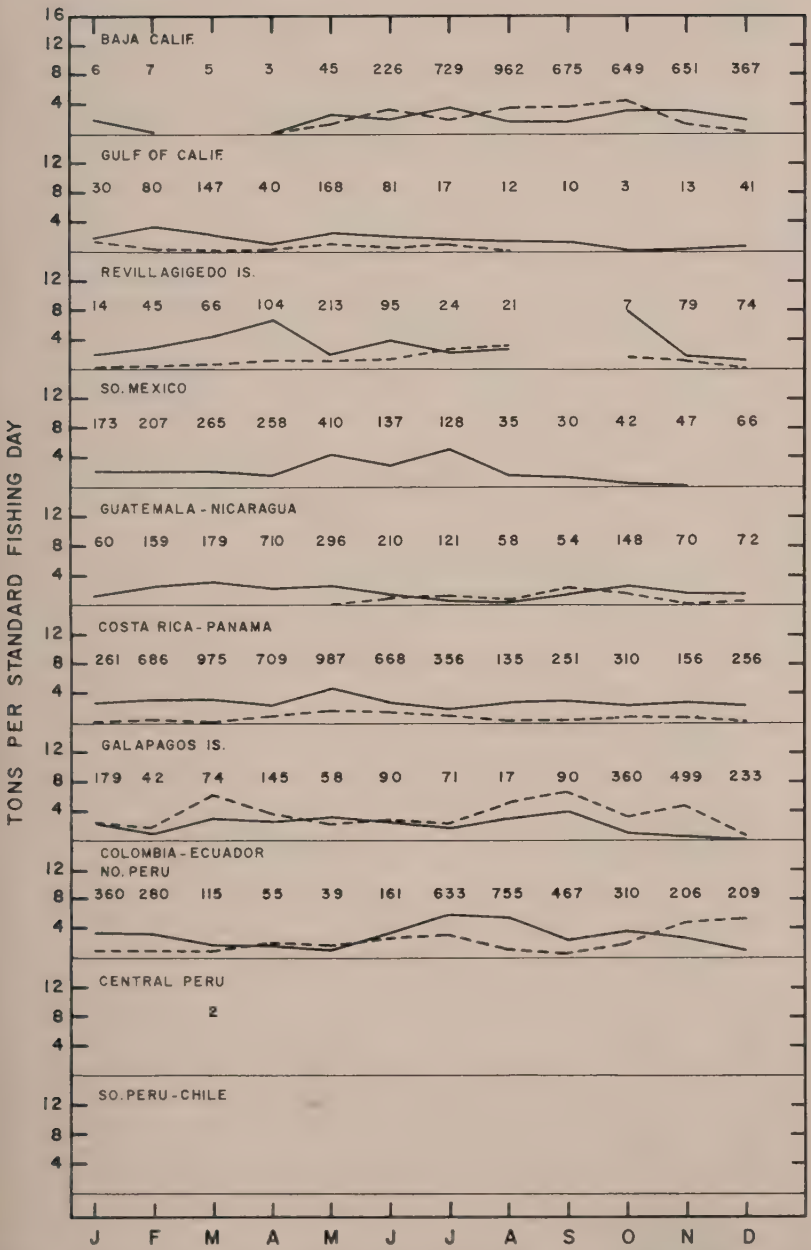


FIGURE 3. Monthly values of catch-per-standard-day's-fishing, for baitboats by major geographical areas, 1951 Numbers for each month indicate effort logged in standard days (see p. 183). Solid line — yellowfin; broken line — skipjack.

FIGURA 3. Valores mensuales de la pesca por día estándar de actividad, para los barcos de carnada, por áreas geográficas mayores, en el año 1951. Los números correspondientes a cada mes indican el esfuerzo registrado en los cuadernos de bitácora en días estándar (ver pág. 225). La línea ininterrumpida correspondiente al atún aleta amarilla y la línea a guiones al barrilete.



IGURE 4. Monthly values of catch-per-standard-day's-fishing, for baitboats by major geographical areas, 1952. Numbers for each month indicate effort logged in standard days (see p. 183). Solid line — yellowfin; broken line — skipjack.

IGURA 4. Valores mensuales de la pesca por día estándar de actividad, para los barcos de carnada, por áreas geográficas mayores, en el año 1952. Los números correspondientes a cada mes indican el esfuerzo registrado en los cuadernos de bitácora en días estándar (ver pág. 225). La línea ininterrumpida correspondiente al atún aleta amarilla y la línea a guiones al barrilete.

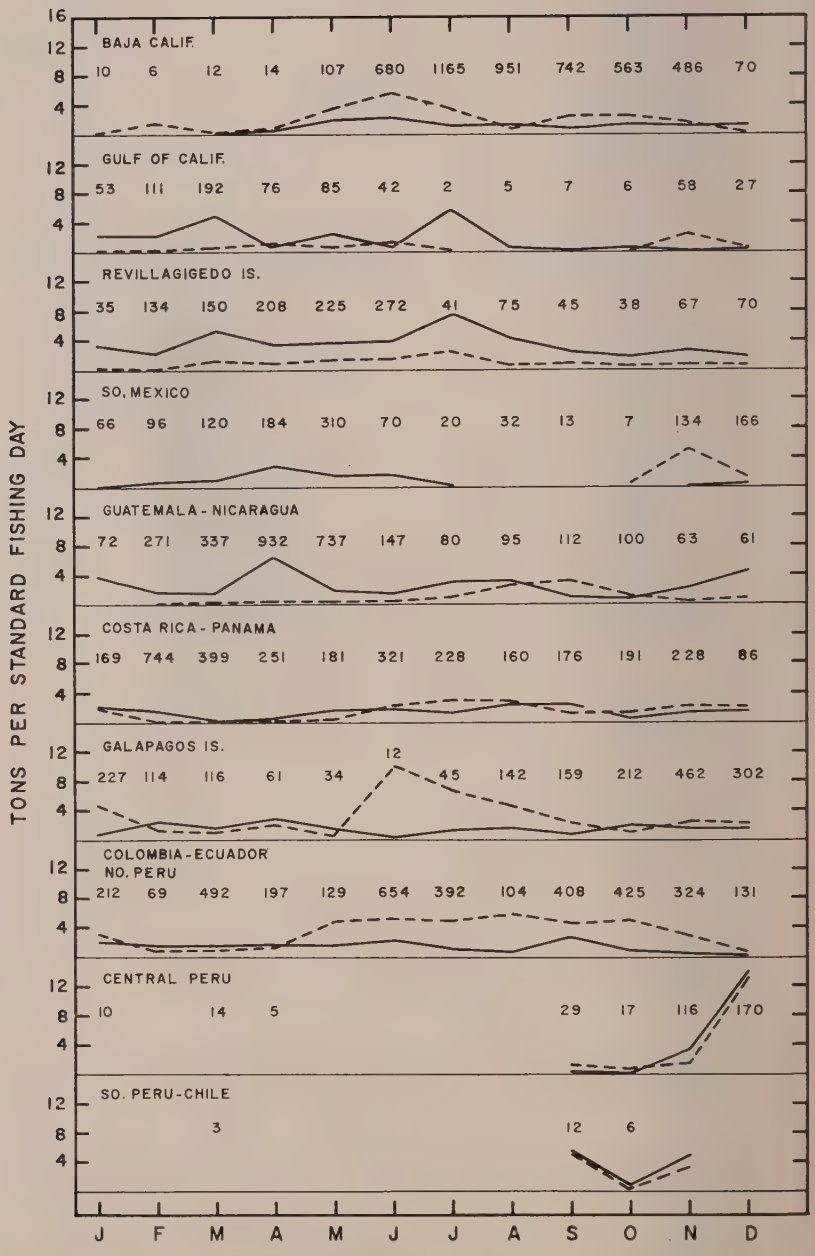
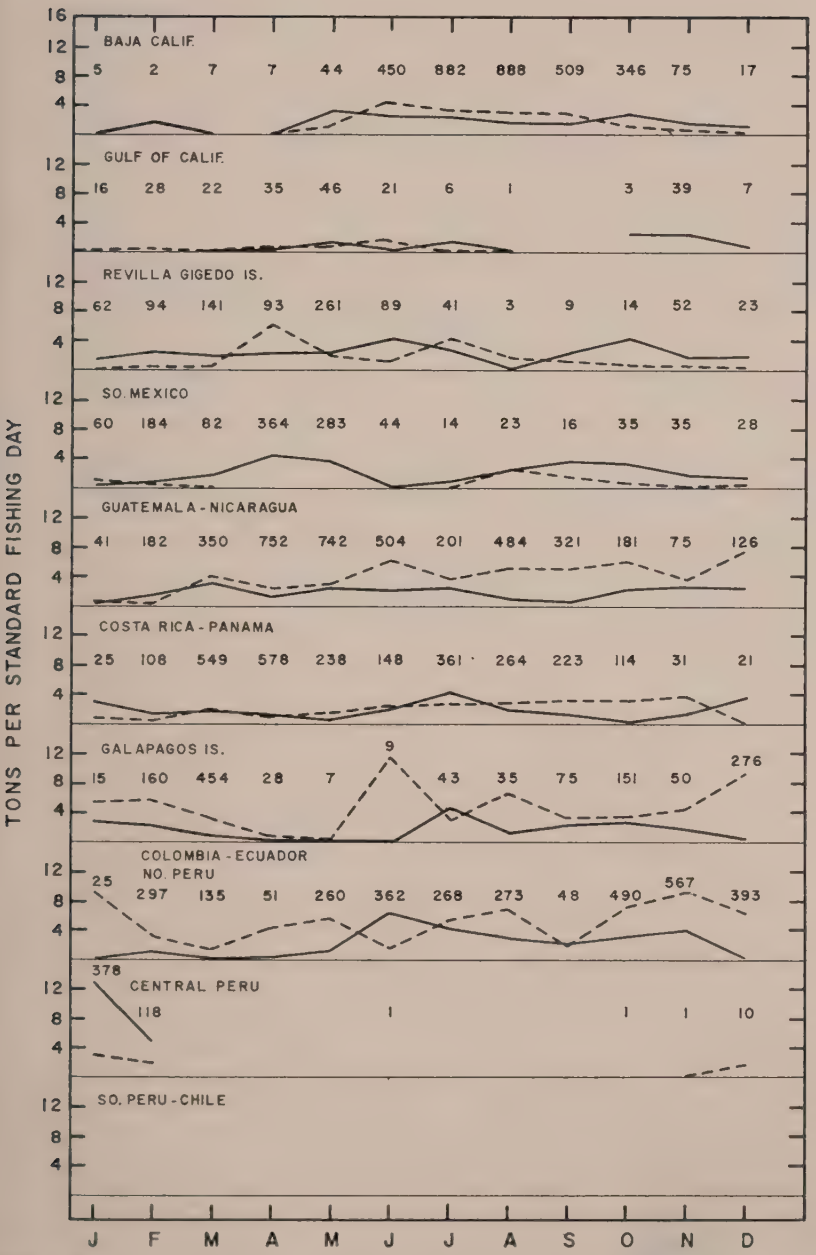


FIGURE 5. Monthly values of catch-per-standard-day's-fishing, for baitboats by major geographical areas, 1953. Numbers for each month indicate effort logged in standard days (see p. 183). Solid line — yellowfin; broken line — skipjack.

FIGURA 5. Valores mensuales de la pesca por día estándar de actividad, para los barcos de carnada, por áreas geográficas mayores, en el año 1953. Los números correspondientes a cada mes indican el esfuerzo registrado en los cuadernos de bitácora en días estándar (ver pág. 225). La línea ininterrumpida correspondiente al atún aleta amarilla y la línea a guiones al barrilete.



GURE 6. Monthly values of catch-per-standard-day's-fishing, for baitboats by major geographical areas, 1954. Numbers for each month indicate effort logged in standard days (see p. 183). Solid line — yellowfin; broken line — skipjack.

GURA 6. Valores mensuales de la pesca por día estándar de actividad, para los barcos de carnada, por áreas geográficas mayores, en el año 1954. Los números correspondientes a cada mes indican el esfuerzo registrado en los cuadernos de bitácora en días estándar (ver pág. 225). La línea ininterrumpida correspondiente al atún aleta amarilla y la línea a guiones al barrilete.

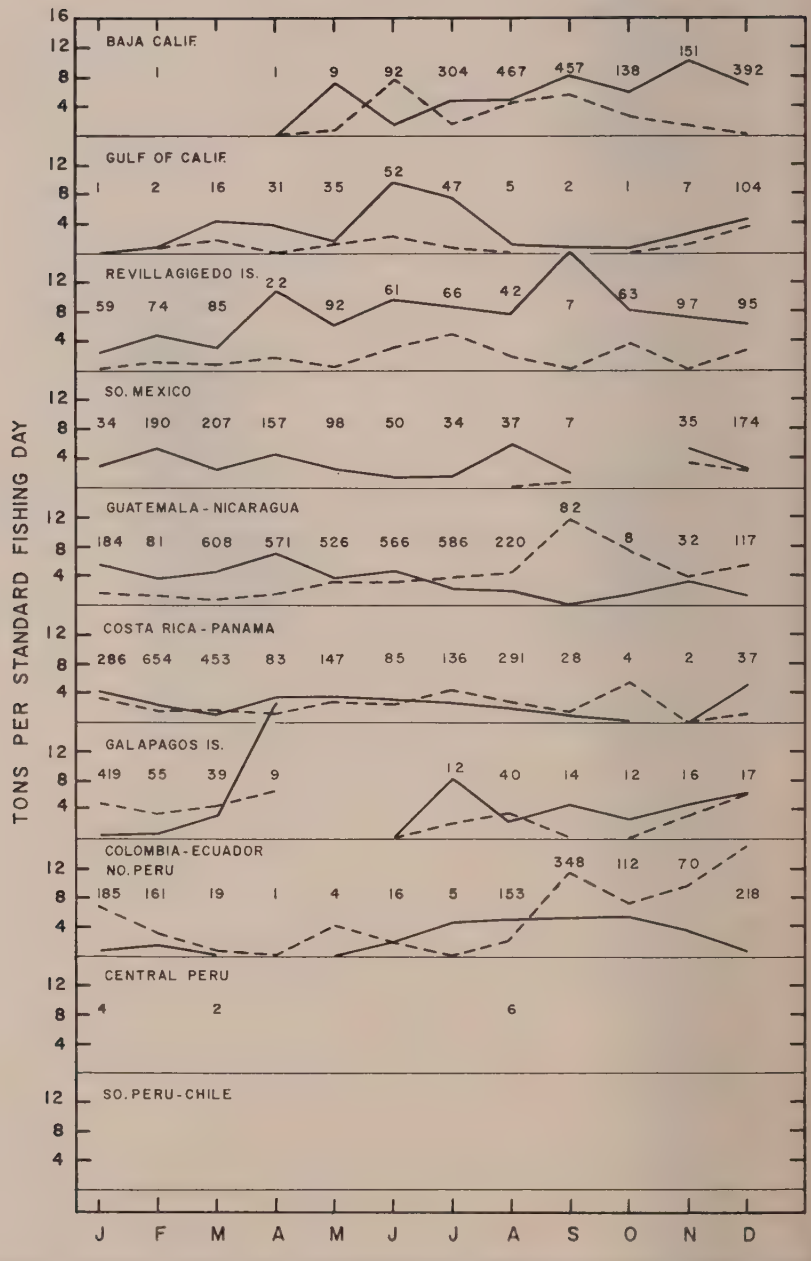
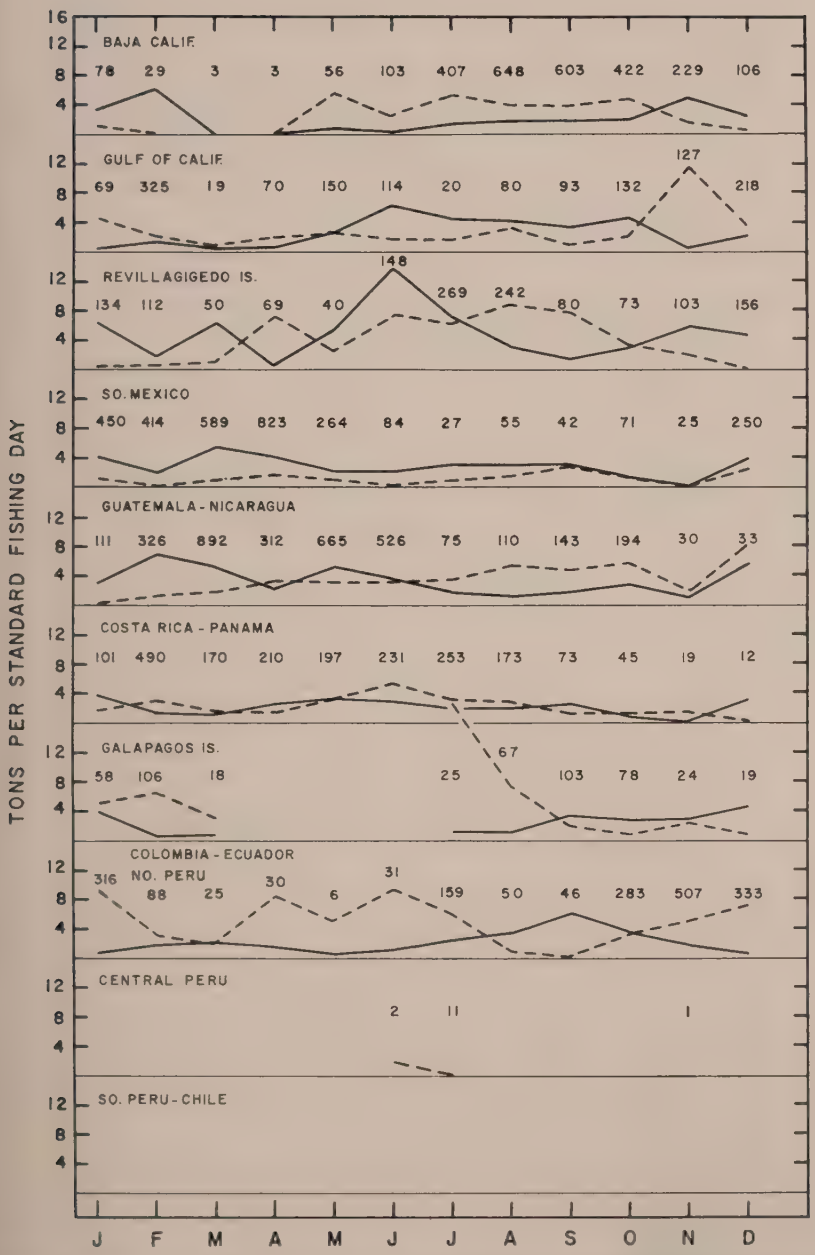


FIGURE 7. Monthly values of catch-per-standard-day's fishing, for baitboats by major geographical areas, 1955. Numbers for each month indicate effort logged in standard days (see p. 183). Solid line — yellowfin; broken line — skipjack.

FIGURA 7. Valores mensuales de la pesca por día estándar de actividad, para lo sbarcos de carnada, por áreas geográficas mayores, en el año 1955. Los números correspondientes a cada mes indican el esfuerzo registrado en los cuadernos de bitácora en días estándar (ver pág. 225). La línea ininterrumpida correspondiente al atún aleta amarilla y la línea a guiones al barrilete.



GURE 8. Monthly values of catch-per-standard-day's-fishing, for baitboats by major geographical areas, 1956. Numbers for each month indicate effort logged in standard days (see p. 183). Solid line — yellowfin; broken line — skipjack.

GURA 8. Valores mensuales de la pesca por día estándar de actividad, para los barcos de carnada, por áreas geográficas mayores, en el año 1956. Los números correspondientes a cada mes indican el esfuerzo registrado en los cuadernos de bitácora en días estándar (ver pág. 225). La línea ininterrumpida correspondiente al atún aleta amarilla y la línea a guiones al barrilete.

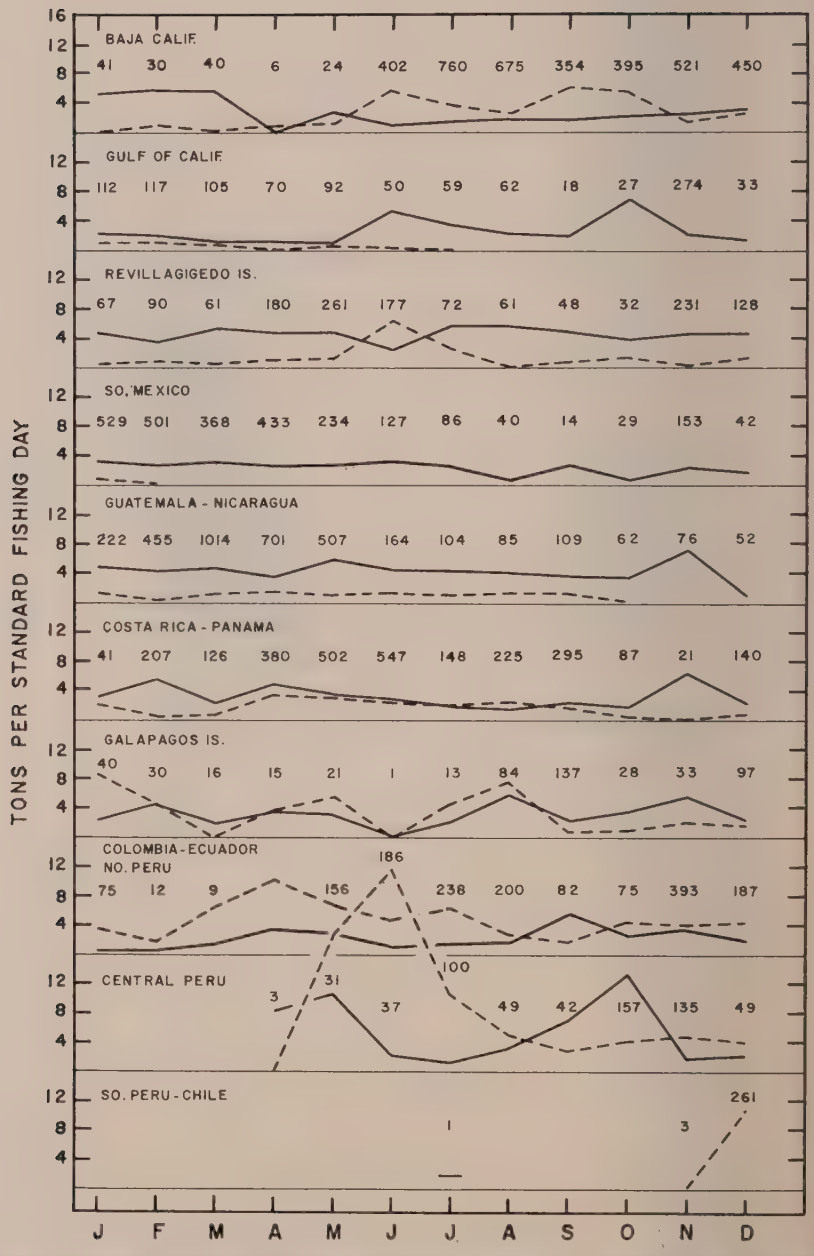
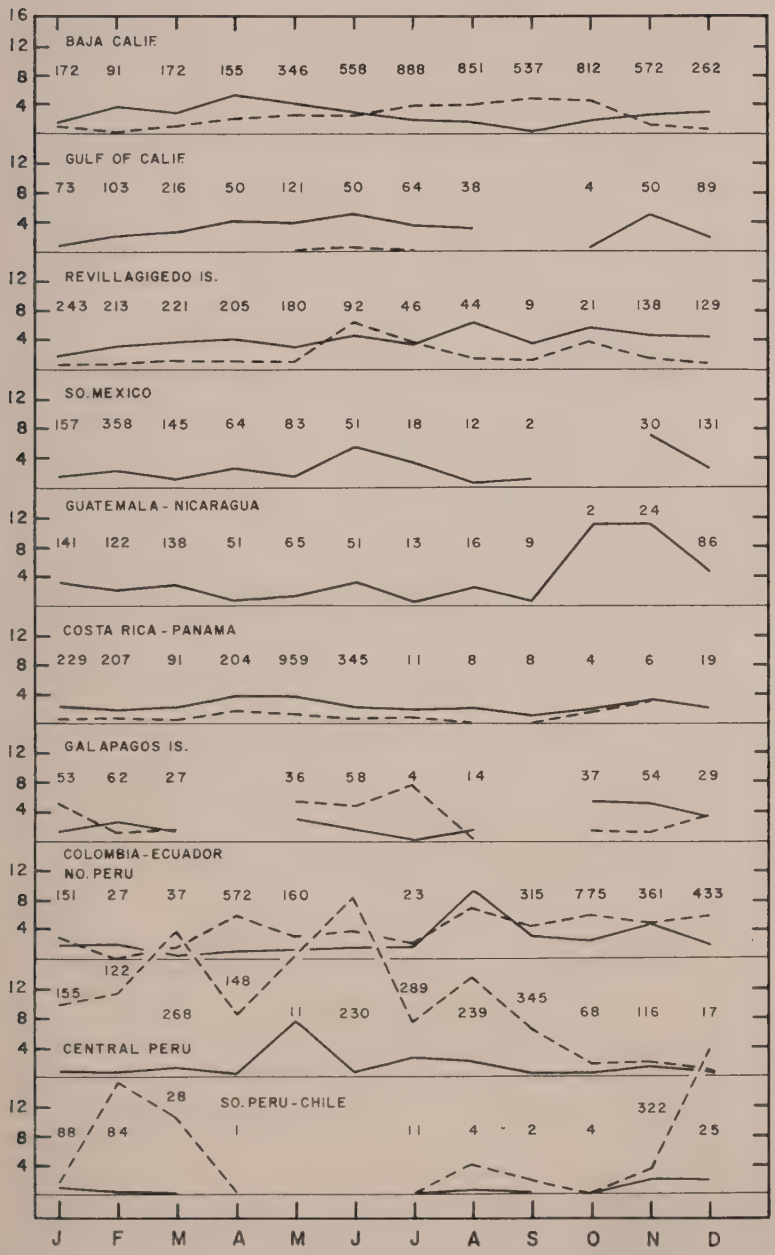


FIGURE 9. Monthly values of catch-per-standard-day'sfishing, for baitboats by major geographical areas, 1957. Numbers for each month indicate effort logged in standard days (see p. 183). Solid line — yellowfin; broken line — skipjack.

FIGURA 9. Valores mensuales de la pesca por día estándar de actividad, para los barcos de carnada, por áreas geográficas mayores, en el año 1957. Los números correspondientes a cada mes indican el esfuerzo registrado en los cuadernos de bitácora en días estándar (ver pág. 225). La línea ininterrumpida correspondiente al atún aleta amarilla y la línea a guiones al barrilete.



IGURE 10. Monthly values of catch-per-standard-day's-fishing, for baitboats by major geographical areas, 1958. Numbers for each month indicate effort logged in standard days (see p. 183). Solid line — yellowfin; broken line — skipjack.

IGURA 10. Valores mensuales de la pesca por día estándar de actividad, para los barcos de carnada, por áreas geográficas mayores, en el año 1958. Los números correspondientes a cada mes indican el esfuerzo registrado en los cuadernos de bitácora en días estándar (ver pág. 225). La línea ininterrumpida corresponde al atún aleta amarilla y la línea a guiones al barrilete.

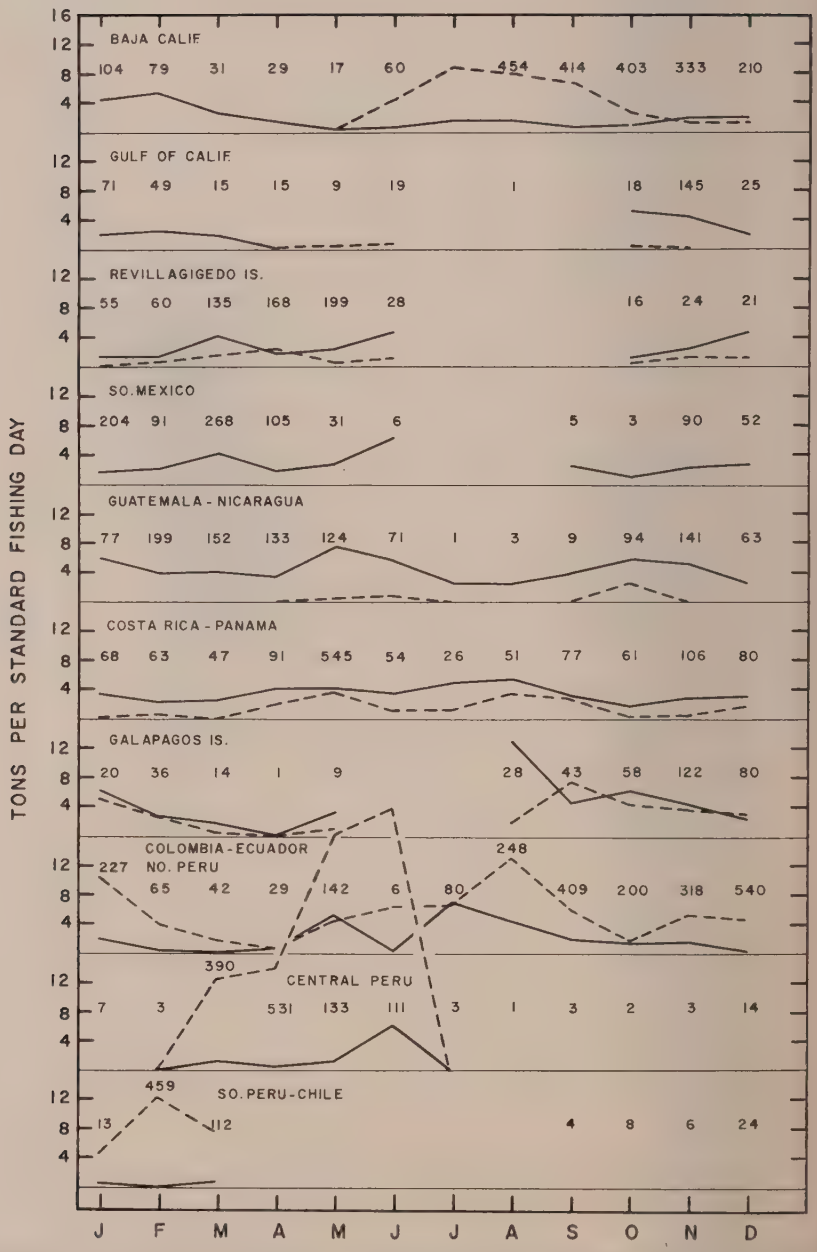
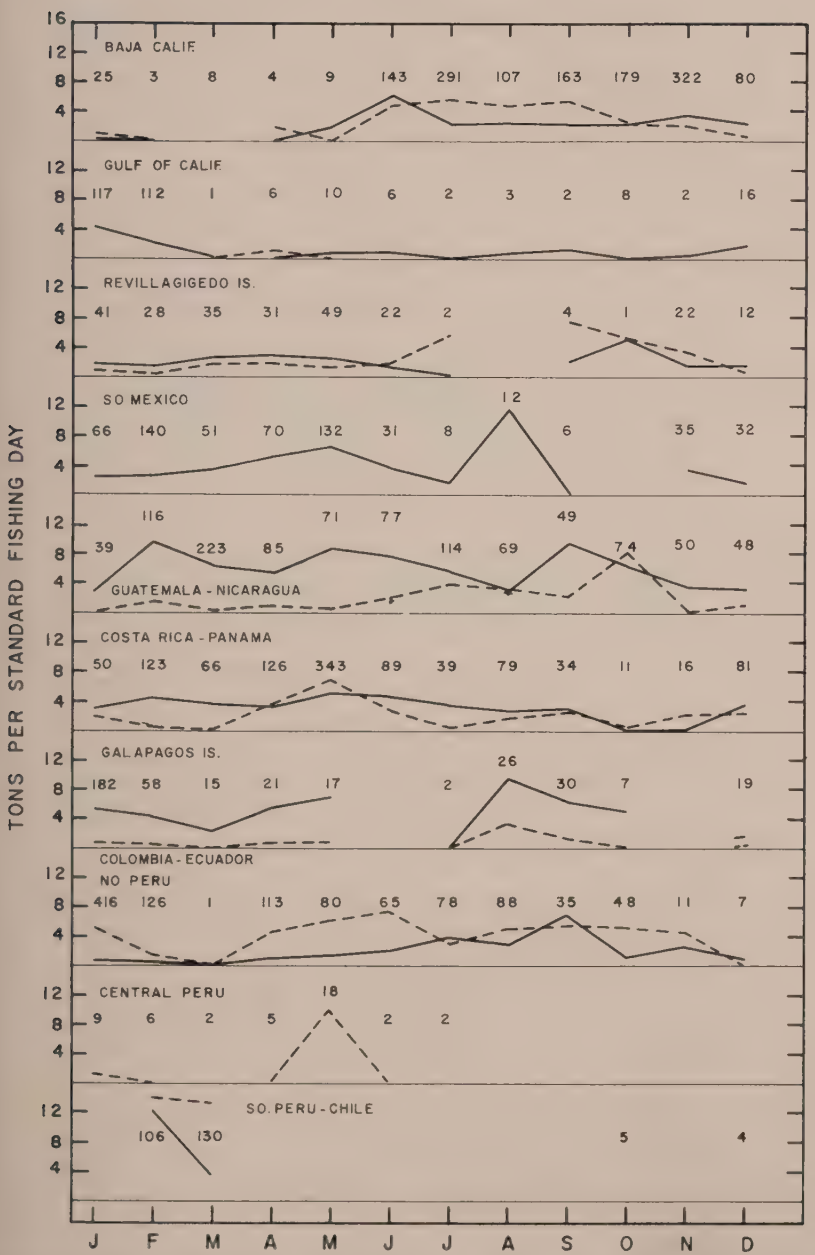


FIGURE 11. Monthly values of catch-per-standard-day's-fishing, for baitboats by major geographical areas, 1959. Numbers for each month indicate effort logged in standard days (see p. 183). Solid line — yellowfin; broken line — skipjack.

FIGURA 11. Valores mensuales de la pesca por día estándar de actividad, para los barcos de carnada, por áreas geográficas mayores, en el año 1959. Los números correspondientes a cada mes indican el esfuerzo registrado en los cuadernos de bitácora en días estándar (ver pág. 225). La línea ininterrumpida corresponde al atún aleta amarilla y la línea a guiones al barrilete.



GURE 12. Monthly values of catch-per-standard-day's-fishing, for baitboats by major geographical areas, 1960. Numbers for each month indicate effort logged in standard days (see p. 183). Solid line — yellowfin; broken line — skipjack.

GURA 12. Valores mensuales de la pesca por día estándar de actividad, para los barcos de carnada, por áreas geográficas mayores, en el año 1960. Los números correspondientes a cada mes indican el esfuerzo registrado en los cuadernos de bitácora en días estándar (ver pág. 225). La línea ininterrumpida corresponde al atún aleta amarilla y la línea a guiones al barrilete.

TABLES — TABLAS

Table 1. Standard days fished (SDF) and catch-per-standard-day's-fishing for yellowfin (YF/SDF) and for skipjack (SJ/SDF) by five-degree area and month for baitboats, 1951-1960.

Tabla 1. Días estándar de pesca (SDF) y pesca de atún aleta amarilla por día estándar de actividad (YF/SDF) y pesca de barrilete por día estándar de actividad (SJ/SDF) por área de cinco grados y por mes, para los barcos de carnada, en el período 1951-1960.

Table 2. Standard days fished (SDF) and catch-per-standard-day's-fishing for yellowfin (YF/SDF) and for skipjack (SJ/SDF) by five-degree area and month for purse seiners, 1953-1960.

Tabla 2. Días estándar de pesca (SDF) y pesca de atún aleta amarilla por día estándar de actividad (YS/SDF) y pesca de barrilete por día estándar de actividad (SJ/SDF) por área de cinco grados y por mes, para los barcos rederos, en el período 1953-1960.

BAITBOATS

FIVE-DEGREE AREA	MONTH	1951 SDF	1951 YF/SDF	1951 SJ/SDF	1952 SDF	1952 YF/SDF	1952 SJ/SDF	1953 SDF	1953 YF/SDF	1953 SJ/SDF	1954 SDF	1954 YF/SDF	1954 SJ/SDF	1955 SDF	1955 YF/SDF	1955 SJ/SDF	1956 SDF	1956 YF/SDF	1956 SJ/SDF	1957 SDF	1957 YF/SDF	1957 SJ/SDF	1958 SDF	1958 YF/SDF	1958 SJ/SDF	1959 SDF	1959 YF/SDF	1959 SJ/SDF	1960 SDF	1960 YF/SDF	1960 SJ/SDF
00 75	1	28.9	5.1	3.5	72.0	5.2	.2	102.9	1.7	3.7	3.6	.1	4.9	17.5	2.0	6.0	17.3	2.6	1.3	10.0	.7	2.8	93.4	2.7	1.7	12.7	1.6	.0	34.8	.5	4.0
00 80	1	1.0	.0	.0	23.0	2.6	.0	11.1	.4	1.6	2.4	2.9	.0	11.3	.7	.0	7.0	3.7	.1	1.8	.0	.0	23.0	.7	.9	1.8	.0	.0	10.3	.1	2.1
00 85	1	1.0	.0	.0	7.9	1.5	.0	6.5	.0	2.0	1.2	.0	.0	60.3	.1	4.7	2.9	.0	.0	1.5	1.3	.0	.5	.0	1.0	1.1	3.6	.0	1.8	.0	.0
00 90	1	44.9	1.0	3.1	87.4	1.7	3.6	193.6	.8	5.8	9.9	4.8	8.4	256.3	.7	5.5	40.6	4.6	7.3	35.0	2.8	9.5	47.5	1.5	5.5	14.9	5.2	7.0	121.3	4.4	.4
05 75	1	.0	.0	.0	5.5	.0	.0	35.2	1.2	.7	1.2	.0	.0	15.7	7.1	3.8	31.2	3.8	2.1	3.0	.0	.0	35.2	.6	.3	7.2	1.8	.0	5.2	.6	.2
05 80	1	26.2	3.6	.7	106.9	1.8	1.0	64.9	.5	4.8	12.4	3.7	2.1	169.8	3.0	4.4	47.1	4.9	1.4	8.4	.4	.0	117.1	2.8	.9	25.4	4.3	.0	12.2	1.8	.0
05 85	1	17.0	2.7	1.6	148.5	3.7	.1	69.3	4.1	.4	8.9	4.0	.1	100.2	6.1	2.6	23.0	2.2	2.7	29.2	4.3	2.9	76.4	2.8	.3	35.1	3.3	.5	32.6	3.7	2.7
05 90	1	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
05 95	1	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
10 85	1	41.9	2.3	1.8	30.0	1.0	.0	44.4	4.7	.1	14.4	.5	1.8	83.0	3.1	3.7	67.0	2.4	.4	22.3	.9	10.1	50.5	2.9	.2	21.1	2.4	.0	6.0	3.0	.2
10 90	1	7.6	.0	.0	26.5	.9	.0	21.6	2.8	.1	7.0	.0	.0	83.3	8.9	.2	21.1	1.8	.0	82.4	6.1	.0	22.8	2.0	.0	33.3	10.1	.0	3.3	.3	.0
10 95	1	.0	.0	.0	.9	2.1	.0	.0	.0	.0	4.4	.1	.0	9.6	1.6	.0	16.7	7.7	.4	102.9	4.4	.6	44.1	3.4	.0	2.0	2.8	.0	2.5	.2	.0
10 100	1	.0	.0	.0	2.1	3.8	.0	2.0	.1	.0	4.9	.0	.0	.8	17.5	.0	.6	.0	.0	6.8	1.4	.0	1.8	.0	.0	2.6	.8	.0	2.7	1.9	.0
10 105	1	4.7	8.6	.0	.8	.0	.0	3.5	.4	.0	10.3	1.3	.0	7.1	5.8	.0	5.5	2.0	.0	7.2	4.8	.0	21.7	5.7	.0	18.3	4.2	.0	24.1	3.4	.0
15 90	1	.8	.0	.0	2.7	.0	.0	3.5	.0	.0	.8	.0	.0	1.3	5.4	.0	3.1	.0	.0	5.0	.2	.0	4.7	.3	.0	2.5	.6	.0	.0	.0	.0
15 95	1	6.0	.0	.6	19.8	.0	.0	17.0	.0	.0	14.5	.7	.6	14.5	2.6	.0	59.6	3.1	.2	189.8	3.2	.9	42.3	2.3	.0	50.8	1.6	.0	12.1	3.2	.0
15 100	1	19.8	.9	.0	74.7	2.0	.0	33.8	.2	.0	30.1	.9	1.9	11.1	2.3	.0	208.3	3.7	.8	274.3	3.4	1.0	64.3	1.3	.1	123.5	1.9	.0	34.4	1.4	.0
15 105	1	8.3	1.4	.0	75.9	2.5	.0	11.2	.7	.1	14.7	.4	.1	3.4	3.7	.0	179.3	5.4	2.6	60.0	2.0	.0	45.3	1.2	.0	27.0	2.2	.0	19.0	4.0	.0
15 110	1	11.2	2.1	.0	14.4	1.9	.0	35.4	3.1	.1	61.9	1.5	.1	58.6	2.4	.2	133.6	6.7	.6	66.5	4.6	.5	150.1	1.2	.2	45.4	1.7	.1	21.5	.2	.0
15 115	1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	92.5	3.0	1.3	9.4	1.1	.0	19.5	3.6	1.9
20 105	1	25.8	.7	2.0	29.9	1.7	1.1	53.0	2.1	.1	16.4	.0	.0	.8	.0	.0	68.7	.4	4.5	112.2	2.1	.8	72.7	.8	.0	71.0	2.0	.0	117.2	4.1	.0
20 110	1	5.3	.1	.0	1.7	.0	.0	7.2	.2	.0	1.6	.0	.0	.0	.0	.0	78.3	3.4	1.1	8.8	.8	.0	61.1	1.3	.0	24.2	.6	.1	10.3	.0	.0
20 115	1	.0	.0	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	10.0	9.4	.0	6.6	3.6	.5	14.4	5.4	.0	.0	.0	.0
25 105	1	.0	.0	.0	1.0	.0	.0	.0	.0	.0	.8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
25 110	1	3.5	8.3	.3	3.3	2.9	.0	1.4	.0	.0	2.2	.0	.0	.0	.0	.0	.0	.0	.0	22.5	5.3	1.0	102.0	1.9	1.5	64.1	5.6	.4	15.0	.7	1.5
25 115	1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.7	.0	3.7	1.5	6.0	.0	.0	.0	.0
205 80	1	16.0	12.1	.0	265.0	2.9	1.2	97.8	2.7	3.3	19.2	.0	11.2	155.8	.3	7.6	291.9	.7	9.8	63.6	.5	3.5	34.5	.6	3.5	212.3	2.3	10.3	371.3	.3	5.3
205 85	1	2.0	.0	.0	2.2	.9	.0	3.0	2.3	.3	1.0	.0	.0	46.5	.6	4.3	7.1	3.1	.6	1.0	.0	.0	2.4	.0	2.5	3.0	11.7	.0	19.5	4.7	1.1
205 90	1	187.1	1.0	7.6	81.9	3.1	1.3	23.8	4.5	.9	2.4	.0	.0	96.0	.9	2.6	7.3	3.1	1.0	2.5	.4	1.2	2.3	.0	.0	.5	.0	.0	38.9	9.0	1.6
210 75	1	.0	.0	.0	.0	.0	.0	4.0	.8	.0	370.8	13.8	3.4	1.4	.0	.0	.0	.0	.0	1.0	.0	.0	141.2	.6	9.0	6.7	.0	.0	4.4	.0	.0
210 80	1	.0	.0	.0	.0	.0	.0	5.6	.2	.0	7.5	.1	.3	2.2	.0	.0	.0	.0	.0	.0	.0	.0	13.3	.2	17.5	.0	.0	.0	4.2	.0	3.1
215 75	1	.0	.0	.0	.0	.0	.0	3.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	11.4	.0	.0	.0	.0	.0	.0	.0	.0
220 70	1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	23.0	.3	1.1	12.7	.3	4.5	.0	.0	.0
220 75	1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5.7	.0	.0	.0	.0	.0	.0	.0	.0
225 70	1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	47.4	1.0	1.5	.0	.0	.0	.0	.0	.0

BAITBOATS

FIVE-DEGREE AREA	MONTH	1951 SDF	1951 YF/SDF	1951 SJ/SDF	1952 SDF	1952 YF/SDF	1952 SJ/SDF	1953 SDF	1953 YF/SDF	1953 SJ/SDF	1954 SDF	1954 YF/SDF	1954 SJ/SDF	1955 SDF	1955 YF/SDF	1955 SJ/SDF	1956 SDF	1956 YF/SDF	1956 SJ/SDF	1957 SDF	1957 YF/SDF	1957 SJ/SDF	1958 SDF	1958 YF/SDF	1958 SJ/SDF	1959 SDF	1959 YF/SDF	1959 SJ/SDF	1960 SDF	1960 YF/SDF	1960 SJ/SDF
00 75	2	26.5	3.4	1.9	87.5	3.0	1.1	37.1	1.0	1.0	34.3	1.0	3.4	126.3	1.8	3.6	43.9	4.0	1.3	3.2	.0	1.6	12.1	3.9	.0	11.4	.8	.1	28.3	.5	2.2
00 80	2	1.0	2.0	2.0	49.0	3.7	.2	11.0	.0	.0	22.1	.6	.5	10.7	.0	.1	26.9	.2	8.8	2.4	.0	.0	5.4	.3	.0	1.6	.0	.0	8.3	1.3	.0
00 85	2	.8	.0	.0	1.2	.0	.0	3.5	.0	.0	4.5	.0	.0	3.1	.0	1.3	6.9	.3	4.1	2.4	.1	.0	3.2	.0	.0	1.0	3.5	.0	2.8	.0	.0
00 90	2	13.5	.3	4.1	30.5	.5	1.5	65.0	.9	2.9	90.4	3.1	5.3	27.4	.5	4.2	90.2	.5	7.5	21.8	3.6	3.8	25.4	1.3	1.0	25.6	2.9	3.9	36.7	4.3	.7
00 105	2	.0	.0	.0	.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
05 75	2	10.5	5.2	2.4	92.1	5.5	.1	96.2	2.9	.1	14.1	.4	.1	207.7	3.3	1.7	153.2	1.5	3.6	4.8	.2	.0	15.3	1.6	.1	10.3	.1	.0	33.7	2.9	1.4
05 80	2	37.6	6.4	1.0	312.0	2.2	.7	259.0	1.0	.6	66.9	2.3	1.2	366.3	1.5	2.0	186.8	1.3	2.1	90.0	5.6	.2	101.0	1.7	.4	26.9	3.1	.1	53.2	5.3	.3
05 85	2	12.1	2.3	6.3	281.7	3.9	.1	388.4	2.1	.1	26.9	.7	.4	79.8	2.6	1.1	149.5	1.7	4.3	112.2	5.7	.6	90.8	2.0	.7	24.1	2.9	1.5	36.3	5.2	.3
05 105	2	.0	.0	.0	.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
05 115	2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	.0	.0	.0	.0
10 85	2	23.4	1.6	14.8	106.6	3.3	.0	214.0	2.0	.1	65.7	2.3	1.6	34.6	.9	2.8	69.9	2.0	.9	48.4	1.4	.4	32.6	.5	.0	21.3	.7	.0	75.9	12.8	2.3
10 90	2	.8	.0	.0	37.6	.5	.0	52.4	.2	.0	52.6	1.3	.1	13.4	.3	.0	40.6	3.2	.6	306.9	5.1	.6	35.9	.8	.0	129.2	4.6	.0	23.7	3.0	.2
10 95	2	.0	.0	.0	3.4	2.8	.0	1.2	.0	.0	54.9	.6	.4	32.4	7.6	.3	193.6	9.7	1.8	54.9	1.9	.0	25.2	1.3	.0	40.8	3.2	.0	2.2	3.4	.0
10 100	2	.0	.0	.0	1.7	.3	.0	.4	.0	.0	6.3	.3	.3	.5	.0	.0	10.4	2.0	.6	30.3	3.2	.0	2.1	.0	.0	.0	.0	.0	.0	.0	.0
10 105	2	17.8	9.0	.0	10.1	1.7	.0	2.5	.0	.0	1.6	.0	.0	.0	.0	.0	11.6	9.8	.2	14.4	4.5	.0	25.9	6.0	.0	8.0	6.0	.0	13.9	4.2	.0
10 110	2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.6	38.3	1.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
15 90	2	.0	.0	.0	5.6	.0	.0	16.1	.0	.0	13.0	5.0	.0	1.2	.0	.0	2.2	.0	.0	12.5	2.5	.0	5.0	1.0	.0	6.3	1.3	.0	5.5	.6	.0
15 95	2	1.7	.0	.0	86.8	3.2	.0	41.6	.5	.1	30.9	.3	.3	42.4	3.1	.1	65.3	2.6	.3	127.2	2.3	.1	136.1	1.9	.0	32.7	1.0	.0	41.5	2.4	.0
15 100	2	22.7	6.4	.0	75.9	1.1	.0	26.9	.1	.0	121.4	.7	1.3	108.7	5.9	.1	128.4	1.2	.0	275.7	2.6	.1	194.3	2.8	.0	36.5	3.6	.0	82.7	3.4	.0
15 105	2	37.5	4.5	.0	38.4	1.2	.0	11.2	1.4	.0	19.0	.4	.3	37.5	7.1	.2	218.5	2.6	.5	85.8	2.8	.1	22.5	.8	.0	17.5	1.3	.0	10.5	.1	.0
15 110	2	33.0	2.5	.0	45.2	3.1	.2	134.3	2.1	.0	94.1	2.7	.5	74.1	4.8	1.2	112.3	2.0	.5	89.9	3.3	.9	156.5	2.6	.7	57.9	1.7	.7	22.1	1.4	.0
15 115	2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	56.9	5.0	1.1	2.0	1.8	.0	6.0	7.2	2.2
20 105	2	47.7	3.0	2.1	80.4	3.4	.1	110.7	2.1	.2	27.8	.0	.2	2.2	.5	.5	324.8	1.7	2.4	117.4	1.9	.9	102.6	2.1	.0	49.2	2.5	.0	112.1	2.2	.0
20 110	2	1.4	.0	.0	4.5	.0	.0	4.7	.0	1.8	.8	.0	.0	1.0	.0	.0	28.2	6.4	.2	25.7	5.9	.9	50.0	2.1	.1	11.5	.1	.0	2.2	.0	.0
20 115	2	.0	.0	.0	.0	.0	.0	.6	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0	3.0	8.7	.0	.8	.0	.0	.8	.0	.0	.0	.0	.0
25 105	2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.1	8.2	.0	.0	.0	.0	.0	.0	.0
25 110	2	1.9	.0	.0	2.5	.0	.0	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.6	.0	.0	39.5	5.1	.1	67.1	6.4	.2	.4	.0	.0
25 115	2	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	3.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
205 80	2	11.0	9.5	.0	143.5	3.0	.9	20.5	2.9	2.3	241.0	1.8	3.7	23.5	.0	1.9	17.6	.0	.5	6.0	.0	2.3	9.7	.1	.0	51.9	.5	5.1	89.3	.2	1.6
205 85	2	.6	.0	.8	.6	.3	.0	3.6	.6	.0	7.7	.3	17.9	3.1	.0	.0	5.1	1.0	.2	.0	.0	.0	2.7	.0	.0	2.8	.4	3.9	3.9	2.1	.0
205 90	2	22.3	.6	14.5	19.2	2.1	2.1	42.0	5.3	.8	57.4	2.4	5.7	21.7	1.2	3.0	3.8	.0	.0	5.3	10.9	9.6	30.2	4.0	1.5	6.7	3.7	.0	14.6	5.6	.2
210 75	2	.0	.0	.0	.0	.0	.0	.0	.0	.0	96.4	6.7	2.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	115.4	.4	11.5	3.2	.0	.0	2.8	.0	.0
210 80	2	.0	.0	.0	.0	.0	.0	.0	.0	.0	21.9	.6	1.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	6.4	.9	5.7	.0	.0	.0	3.2	.0	.0
215 75	2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	.0	.6	.0	.0	.0	.0	.0
220 70	2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	76.1	.1	16.1	441.7	.1	12.4	42.7	2.3	8.0
225 70	2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	6.4	.0	10.6	16.7	.0	11.6	62.7	19.2	18.7
225 80	2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0

BAITBOATS

FIVE-DEGREE AREA		MONTH	1951			1952			1953			1954			1955			1956			1957			1958			1959			1960		
			SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF
00	75	3	1.0	.0	.0	59.7	2.2	1.6	97.6	.7	.1	35.5	.6	1.0	11.9	.0	.8	15.9	3.5	.1	5.3	.8	10.9	10.0	.2	2.0	8.5	.4	.1	.0	.0	.0
00	80	3	.0	.0	.0	26.3	2.4	.1	118.2	1.4	2.6	31.6	.2	.1	4.6	.0	.0	8.2	.1	6.5	4.1	1.6	.9	12.5	1.5	.5	7.5	.3	.1	1.2	.0	.0
00	85	3	.0	.0	.0	.0	.0	.0	4.8	.1	.0	18.6	.6	6.0	1.8	.0	5.6	.0	.0	.0	.6	.0	.0	1.7	.0	4.1	.0	.0	.0	.0	.0	.0
00	90	3	.0	.0	.0	25.1	1.5	.8	38.7	1.0	1.0	258.5	1.5	3.4	30.7	2.4	3.9	9.6	1.1	2.0	10.2	.0	.1	18.5	1.2	1.5	6.1	3.0	.9	10.5	1.8	.1
05	75	3	.0	.0	.0	289.7	4.2	.1	43.5	.1	.0	115.3	3.7	2.7	71.5	4.0	.1	37.7	2.0	1.4	5.8	1.4	.0	22.4	2.9	.3	7.2	2.9	.1	8.2	2.6	.9
05	80	3	5.6	.8	.3	374.7	1.6	.7	161.2	.5	.1	307.9	1.3	2.9	283.2	.5	1.9	84.2	.8	2.1	64.3	2.8	.6	39.9	.9	.2	18.9	1.2	.0	24.7	2.6	.0
05	85	3	3.1	1.3	.0	310.1	3.6	.2	183.8	.7	.0	125.9	3.6	.4	98.6	.9	.4	48.3	1.5	.9	55.8	1.5	1.0	27.7	3.0	.2	21.1	4.3	.3	32.6	4.7	.0
05	90	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	4.0	.0	.0	.0	.0	.0	.0	.0
10	85	3	13.7	.9	.5	492.2	3.6	.1	257.4	1.4	.3	230.6	3.5	6.2	516.6	4.9	.7	226.9	1.7	1.6	210.4	4.3	1.2	38.9	3.5	.0	19.9	2.1	.0	76.6	4.7	.6
10	90	3	3.0	.0	.0	67.7	.7	.0	69.5	1.6	.1	42.5	1.2	.0	61.2	1.2	1.0	295.0	5.6	3.3	774.5	4.8	1.0	40.6	1.7	.0	94.8	4.7	.0	105.0	8.0	.1
10	95	3	.4	.0	.0	12.4	2.0	.0	3.8	5.0	.0	51.0	4.0	.2	26.5	4.2	.0	313.2	7.5	1.0	22.6	.6	.0	6.1	.7	.0	30.6	4.1	.0	12.9	3.9	.0
10	100	3	.0	.0	.0	2.1	.0	.0	2.2	.0	.0	10.7	.5	.2	1.0	3.0	.0	51.2	6.9	.1	.0	.0	.0	3.6	1.1	.0	4.6	10.0	.0	22.8	7.0	.0
10	105	3	2.2	28.9	.0	3.8	.1	.0	4.0	.0	.8	14.9	6.9	.0	2.4	.4	.0	5.9	3.3	.1	6.7	3.9	.0	49.1	3.8	.0	2.0	.0	.0	5.9	11.2	.0
10	110	3	.0	.0	.0	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
15	90	3	1.0	.0	.0	8.0	.6	.0	7.6	2.1	.1	9.7	.7	.0	5.8	.0	.0	10.4	1.8	1.0	31.5	2.0	.0	10.6	2.1	.0	4.0	.8	.0	3.0	.0	.0
15	95	3	4.5	.0	.0	151.0	2.9	.0	50.4	.8	.1	30.0	1.8	.1	89.9	2.9	.3	297.6	6.2	.9	62.2	2.4	.0	57.8	2.0	.0	72.9	4.1	.0	19.6	2.5	.0
15	100	3	8.1	.8	.0	75.3	.4	.0	42.3	.1	.2	37.9	2.3	.8	79.8	1.7	.0	243.1	5.7	.7	223.8	3.8	.0	61.0	.3	.0	171.1	4.2	.0	27.9	3.8	.0
15	105	3	16.6	6.6	.1	30.8	2.4	.0	19.9	2.0	.6	4.5	.2	.0	31.3	3.3	.2	37.6	1.6	2.6	50.5	2.3	.0	15.1	.0	.0	20.0	3.7	.0	.0	.0	.0
15	110	3	1.1	3.6	.0	66.3	4.2	.4	149.5	5.1	1.1	140.6	2.1	.8	84.6	3.1	.8	50.2	6.4	1.0	60.6	5.2	.6	170.4	3.4	.7	133.0	4.1	1.4	26.9	2.6	1.2
15	115	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	50.2	5.7	2.3	2.0	.0	.0	8.0	3.4	2.9
20	105	3	14.3	2.7	4.1	146.7	2.8	.3	191.6	4.9	.3	22.3	.0	.0	15.7	4.4	1.8	18.6	.5	.7	105.2	1.2	.8	216.1	2.6	.0	14.8	1.9	.0	1.2	.0	.0
20	110	3	2.8	.0	.0	3.7	.5	.0	10.5	.3	.4	5.2	.0	.0	.0	.0	.0	.8	.0	.0	39.7	5.6	.1	147.9	2.3	.6	8.3	5.5	.0	.8	.0	.0
20	115	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	16.8	5.9	.0	4.9	.8	.0	.0	.0	.0
25	105	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.0	.0	.0	.0	.0	.0	1.7	3.6	.0	.0	.0	.0	.0	.0	.0
25	110	3	1.7	.0	.0	3.3	.0	.0	1.1	.0	.0	1.6	.0	.0	.0	.0	.0	.0	.0	.0	.4	.0	.0	5.5	2.2	4.4	18.1	1.2	.0	.0	.0	.0
205	80	3	.0	.0	.0	27.3	.2	.0	276.6	2.1	1.2	68.2	1.3	2.4	2.0	.0	.0	.6	.0	.0	.0	.0	.0	14.6	.1	1.4	26.2	.3	2.7	.0	.0	.0
205	85	3	.0	.0	.0	1.8	.6	.0	.6	.0	.0	15.7	.1	.0	.0	.0	.0	8.2	.5	4.8	.6	.0	.0	.0	.0	.0	2.8	2.1	.7	2.4	.0	.0
205	90	3	.0	.0	.0	47.0	4.2	9.3	72.0	2.5	1.8	161.2	.9	3.7	6.4	9.1	6.7	.0	.0	.0	4.1	6.1	.0	6.3	1.7	.0	5.2	.4	.0	1.7	5.4	.1
210	75	3	.0	.0	.0	.0	.0	.0	1.8	.6	.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	258.3	1.0	20.1	388.6	1.4	12.5	2.4	.0	.0
210	80	3	.0	.0	.0	1.5	.0	.0	12.3	.0	.0	.0	.0	.0	2.0	.0	.0	.0	.0	.0	.0	.0	.0	9.9	.5	4.4	1.8	1.7	6.7	.0	.0	.0
215	75	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	18.6	.0	14.6	2.4	.0	3.8	2.0	.0	14.0
220	70	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	8.4	.0	2.1	107.0	.8	7.6	90.4	4.4	11.3
220	75	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.6	.0	.0	1.2	.0	.0	2.4	.0	.0
220	80	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.3	.0	.0
225	70	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	4.2	28.0	2.8	23.2
225	75	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.3	.0	.0
225	80	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.3	.0	.0
230	75	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.6	.0	.0
230	80	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.6	.0	.0

BAITBOATS

FIVE-DEGREE AREA		MONTH	1951 SDF	1951 YF/SDF	1951 SJ/SDF	1952 SDF	1952 YF/SDF	1952 SJ/SDF	1953 SDF	1953 YF/SDF	1953 SJ/SDF	1954 SDF	1954 YF/SDF	1954 SJ/SDF	1955 SDF	1955 YF/SDF	1955 SJ/SDF	1956 SDF	1956 YF/SDF	1956 SJ/SDF	1957 SDF	1957 YF/SDF	1957 SJ/SDF	1958 SDF	1958 YF/SDF	1958 SJ/SDF	1959 SDF	1959 YF/SDF	1959 SJ/SDF	1960 SDF	1960 YF/SDF	1960 SJ/SDF
00	75	4	9.2	8.1	10.2	22.7	.7	3.5	78.6	.6	1.9	18.7	.2	4.0	.0	.0	.0	20.1	2.4	10.8	65.7	4.4	10.9	119.4	.4	6.6	3.6	.0	.0	34.8	1.3	4.5
00	80	4	1.0	27.0	.0	23.4	1.5	.9	100.1	2.1	1.0	14.3	.0	.1	1.2	.0	.0	5.8	.0	6.2	18.2	.2	7.2	55.0	1.0	2.7	2.6	.2	.2	38.7	.6	4.9
00	85	4	.0	.0	.0	2.8	.0	.0	6.1	.4	.8	3.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.6	.0	.0	.5	.0	.0
00	90	4	62.5	15.0	1.8	39.6	1.5	1.9	10.5	1.0	.2	20.0	.4	.9	.0	.0	.0	.0	.0	.0	13.3	3.9	4.0	.0	.0	.0	.6	.0	.0	15.3	6.9	.7
05	75	4	1.0	6.0	.0	234.8	5.4	1.5	44.8	.5	.1	115.5	3.4	1.0	27.8	2.4	1.1	11.7	3.2	.9	196.3	7.4	4.5	107.5	3.4	2.8	35.6	4.8	4.4	76.6	3.0	5.7
05	80	4	15.0	.3	6.5	346.0	1.1	.9	130.9	.6	.4	280.0	.8	2.0	23.9	.7	.0	57.5	.7	1.4	119.9	2.3	2.8	56.6	3.8	.1	35.7	4.1	.1	29.9	2.2	.3
05	85	4	18.4	6.3	.8	127.6	.8	.0	74.5	.6	.1	181.8	2.1	1.4	31.7	5.4	1.7	140.9	3.5	1.4	63.7	1.8	1.4	39.8	4.7	.0	19.3	3.1	.9	19.5	4.4	.0
05	90	4	.0	.0	.0	1.0	.0	.0	1.0	.0	.0	1.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
10	85	4	227.4	2.7	8.5	476.9	1.9	.0	360.0	4.5	.7	583.6	1.7	3.1	245.7	6.4	2.1	210.7	2.2	5.0	374.4	3.2	1.9	22.4	.6	.0	19.4	3.5	.7	25.0	2.3	2.6
10	90	4	91.7	.8	1.4	117.9	1.2	.0	177.2	5.6	.2	85.6	1.0	.2	239.1	7.5	.8	29.8	1.4	.6	300.1	3.9	.9	21.8	1.0	.0	74.4	4.0	.0	6.5	6.0	.5
10	95	4	50.6	4.2	.0	91.2	3.9	.0	386.8	9.6	.3	76.2	3.1	1.0	84.3	7.8	1.2	23.6	1.5	1.5	15.2	1.4	.0	4.4	1.1	.0	15.6	2.2	.0	19.9	6.3	.0
10	100	4	21.9	5.7	.2	20.4	6.2	.1	4.6	.0	.2	3.2	3.9	1.6	.0	.0	.0	41.3	4.2	.3	6.2	2.2	.2	.0	.0	.0	4.6	2.0	.0	1.7	3.5	.0
10	105	4	9.2	14.3	2.0	3.7	.0	.0	3.2	.0	.0	3.0	3.7	.0	2.0	33.0	.0	6.7	3.3	.0	5.4	2.8	.0	2.2	.0	.0	19.4	4.9	.0	32.3	7.7	.0
15	90	4	10.9	.0	.0	12.3	1.2	.0	7.9	.6	.0	18.8	.6	.0	8.8	5.6	.2	15.8	2.2	1.9	9.4	.0	.0	6.9	6.5	.0	9.8	1.6	.0	.0	.0	.0
15	95	4	99.8	3.7	.0	104.3	1.8	.0	117.4	3.9	.6	130.0	3.2	.1	73.3	4.5	.1	85.0	3.3	2.4	93.9	1.7	.0	28.2	3.5	.0	25.8	2.0	.0	41.8	6.1	.0
15	100	4	174.4	2.4	.0	127.9	2.3	.0	46.3	1.5	.1	200.8	6.1	.4	66.2	4.8	.3	412.5	3.8	.9	194.6	2.2	.0	17.0	.5	.0	55.7	1.6	.0	21.9	4.4	.0
15	105	4	126.3	2.2	.0	13.5	.7	.0	12.7	.3	.2	13.9	1.8	1.5	9.0	2.4	.0	309.2	4.7	2.9	134.6	3.9	.0	12.0	1.2	.0	13.8	1.6	.0	6.5	.5	.0
15	110	4	108.2	4.5	.1	104.2	6.4	1.0	207.8	3.3	.9	92.9	2.5	6.5	21.6	10.8	1.9	68.7	.8	7.3	179.4	4.3	1.1	165.7	2.2	.7	166.6	2.1	1.4	23.6	1.5	1.0
15	115	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.8	.0	.0	39.5	12.2	2.9	1.7	.0	.0	7.0	7.7	3.1
20	105	4	218.5	.7	1.7	40.0	.9	.2	75.6	.7	.9	34.9	.3	.4	30.9	3.6	.0	69.6	.6	1.8	69.8	1.0	.0	50.2	3.9	.0	14.8	.2	.0	6.4	.0	1.1
20	110	4	18.4	.0	.3	1.2	.0	.0	1.2	4.1	7.6	4.4	.0	.0	.6	.0	.0	2.4	.0	.0	6.1	.0	.3	136.9	4.7	2.0	17.8	.3	.0	3.6	.0	1.8
20	115	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	17.9	8.2	.0	9.9	3.6	.0	.0	.0	.0
25	105	4	4.1	.0	.0	.0	.0	.0	1.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
25	110	4	17.0	.3	.0	1.6	.0	.0	11.8	.3	.1	2.5	.0	.0	.0	.0	.0	.8	.0	.0	.0	.0	.0	.4	.0	.0	.0	.0	.0	.0	.0	.0
25	115	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.8	.0	.0	.0	.0	.0
205	80	4	10.0	25.8	.5	9.3	2.8	.0	18.1	1.2	.4	17.5	2.7	8.9	.0	.0	.0	3.6	.0	.0	1.0	.0	.0	398.1	1.1	5.9	23.0	.7	.7	39.9	1.2	5.0
205	85	4	.0	.0	.0	11.8	.5	8.7	5.7	8.0	1.0	.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	3.6	.0	.0
205	90	4	10.9	1.2	22.6	90.7	3.3	4.2	38.4	3.4	3.1	4.1	.0	.0	9.1	18.4	6.5	.0	.0	.0	1.7	3.8	.0	.0	.0	.0	.0	.0	.0	1.8	6.1	.0
210	75	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.7	8.1	.7	99.4	.3	9.3	432.7	.3	15.3	2.2	.0	.0
210	80	4	.0	.0	.0	.0	.0	.0	4.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	48.3	.1	6.2	98.4	.0	10.5	2.4	.0	.0
215	75	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	.0	.0	.0	.0	.0	.0	.0

BAITBOATS

FIVE-DEGREE AREA		MONTH	1951			1952			1953			1954			1955			1956			1957			1958			1959			1960		
			SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF
00	75	5	31.0	3.8	5.7	14.7	1.0	2.3	20.0	1.0	6.1	64.8	.3	4.7	.0	.0	.0	4.8	.6	6.3	145.9	3.0	7.4	86.9	1.4	3.2	97.5	6.9	4.9	19.4	2.2	2.4
00	80	5	7.2	13.5	.0	12.4	1.5	1.5	101.4	1.8	4.8	73.4	1.0	4.7	4.1	.0	4.1	1.0	.0	.0	9.8	1.7	1.3	16.3	.2	.3	13.8	4.0	.5	9.3	.5	11.4
00	85	5	2.3	.0	9.6	.0	.0	.0	1.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	.0	.0	.0	.0	.0	.0	.0
00	90	5	121.3	3.6	2.2	38.1	1.7	2.2	12.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	21.4	3.0	5.6	24.1	3.8	5.0	6.5	4.1	1.1	14.4	8.1	1.1
00	95	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.6	.0	.0	.0	.0	.0	.0	.0	.0
05	75	5	101.2	8.4	3.1	725.0	5.6	2.1	54.5	3.4	.3	53.9	1.1	2.2	61.8	6.0	4.7	98.8	4.6	5.5	336.2	3.4	4.5	650.8	4.0	1.5	339.8	3.5	6.6	230.5	5.7	7.1
05	80	5	190.1	4.7	.7	213.7	2.1	1.1	64.2	.4	.5	137.3	.9	2.1	50.5	.2	1.6	54.3	1.2	1.1	133.6	2.2	1.7	272.7	3.1	.1	158.2	4.4	.3	105.7	4.5	7.2
05	85	5	95.4	3.0	4.7	48.1	3.4	.1	62.5	1.3	.3	46.9	1.4	.6	34.5	3.5	1.1	43.5	3.1	1.1	31.0	3.4	.2	34.7	3.5	.0	47.0	7.8	.2	6.5	1.4	.2
05	90	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
05	95	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	.0	.0	.0	.0	.0	.0	.0
10	85	5	1017.3	2.5	5.0	111.2	.8	.0	418.9	1.9	1.4	464.9	1.3	4.6	387.6	3.3	4.0	360.5	4.3	3.8	111.2	4.9	1.9	33.8	1.7	.0	86.4	10.3	.6	14.7	4.4	2.9
10	90	5	144.2	4.4	.5	147.1	3.4	.0	151.1	.9	.0	202.0	5.7	1.3	120.4	5.3	.6	288.0	6.5	2.5	316.4	6.4	.7	25.4	.8	.0	22.0	1.9	.1	17.4	15.0	.0
10	95	5	11.3	1.6	.0	28.3	2.8	.0	156.3	3.4	.1	73.2	6.1	.7	7.1	.3	.3	9.4	.9	1.1	75.6	6.1	.0	3.2	.0	.0	.0	.0	.0	29.9	7.9	.0
10	100	5	2.6	3.1	.0	5.4	2.4	.0	7.5	1.2	.0	1.0	.0	.0	4.3	3.3	.0	7.4	5.1	3.2	.4	.0	.0	.0	.0	.0	.0	.0	.0	7.3	7.8	.0
10	105	5	5.9	6.3	.5	4.2	.0	.0	3.0	.8	.0	1.0	.7	.0	6.1	6.3	.8	.0	.0	.0	3.0	9.7	.0	2.2	.7	.0	15.4	1.2	.0	1.7	.9	.0
15	90	5	8.7	.9	.0	115.5	7.5	.0	6.7	.0	.0	12.9	4.6	.9	5.4	.0	.0	7.3	1.1	.0	3.5	.4	.0	7.2	.7	.0	1.9	.0	.0	.0	.0	.0
15	95	5	39.5	1.6	.0	97.5	4.0	.0	161.1	1.8	.0	175.7	4.6	.3	25.4	.7	.0	45.6	1.4	1.2	41.7	3.2	.0	18.3	.4	.0	16.0	4.9	.0	68.1	9.5	.0
15	100	5	168.2	3.4	.0	86.0	.8	.0	103.3	.7	.0	86.8	.4	.0	50.5	2.8	.1	149.3	2.7	1.5	148.0	2.8	.0	45.7	1.7	.0	8.4	.5	.0	54.3	3.4	.0
15	105	5	111.6	2.5	.0	110.8	3.2	.0	38.4	2.5	.1	7.9	1.8	.0	16.4	4.4	.6	61.8	2.1	1.0	40.4	2.3	.0	11.3	1.7	.0	4.7	.0	.0	9.7	2.5	.0
15	110	5	99.3	4.5	.2	212.5	1.8	1.5	224.8	3.6	1.2	261.4	2.7	2.1	91.5	6.9	.4	39.5	5.5	2.6	254.6	4.3	1.0	144.5	2.5	1.1	195.2	2.5	.7	37.8	1.7	.7
15	115	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	6.5	19.1	13.8	35.3	5.5	.4	4.0	3.6	.3	10.9	5.6	3.6
20	105	5	180.3	.3	2.5	168.0	2.6	.7	84.9	2.3	.8	46.0	1.3	.5	34.9	1.5	1.1	150.4	2.9	2.8	92.0	.4	.1	121.1	3.8	.0	9.1	.0	.2	9.5	.6	.0
20	110	5	10.7	2.6	.4	6.7	1.6	.9	103.3	2.1	3.7	43.6	3.3	1.4	8.3	.6	7.9	54.1	.8	5.7	14.6	.1	1.8	303.3	4.1	2.4	11.8	.0	.0	7.1	2.2	.0
20	115	5	.8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	4.0	15.5	.0	27.0	3.2	.5	5.0	1.1	.0	1.1	.0	.0
25	105	5	7.2	.7	.2	19.4	3.0	2.0	1.6	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	.0	3.0	.7	.0	1.7	.0	.0	.0	.0	.0	.0	.0	.0
25	110	5	20.2	.2	1.8	18.9	2.7	.6	2.5	.0	.0	.0	.0	.0	1.0	.0	.0	.9	.0	.0	2.8	.0	.0	13.0	1.3	3.8	.0	.0	.0	.6	.0	.0
25	115	5	.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.8	.0	.0	.0	.0	.0	.0	.0	.0
205	80	5	42.0	16.3	.0	11.5	.2	.0	7.6	3.1	2.8	121.3	3.5	8.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	56.9	.5	3.4	31.0	1.7	5.5	51.0	.8	6.6
205	85	5	.0	.0	.0	6.5	6.6	.9	.0	.0	.0	1.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.4	.0	1.2	.0	.0	1.0	.0	.0
205	90	5	63.8	2.5	7.4	13.4	6.2	2.6	20.5	2.9	1.2	5.7	.0	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	9.9	1.6	7.6	1.2	3.3	.0	1.5	.7	.0
210	75	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	31.1	10.5	18.8	11.2	7.5	16.2	129.1	1.1	33.6	9.7	.0	.0
210	80	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.C	.0	.0	.0	.0	.0	3.4	.0	.9	8.0	.0	9.8

BAITBOATS

FIVE-DEGREE AREA		MONTH	1951			1952			1953			1954			1955			1956			1957			1958			1959			1960		
			SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF
00	75	6	29.6	.5	4.3	106.1	2.5	3.2	180.1	3.0	5.1	36.5	.2	2.8	5.2	.0	3.4	19.6	1.7	13.7	106.6	.6	4.9	30.8	.5	.6	.0	.0	.0	12.1	1.2	4.6
00	80	6	19.3	.3	7.0	29.4	1.5	5.4	263.4	1.9	5.3	58.9	4.1	4.0	7.6	4.0	1.4	4.7	.0	7.0	25.3	2.5	6.3	34.4	.6	2.6	.0	.0	.0	7.0	.0	7.1
00	85	6	2.9	.0	13.6	2.3	.0	.0	.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.5	.0	.0	3.5	.1	.0	.0	.0	.0	.0	.0	.0
00	90	6	30.3	2.2	13.1	49.9	1.3	4.2	7.6	.9	16.4	9.3	.1	11.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	45.8	1.9	5.4	.0	.0	.0	.0	.0	.0
05	75	6	74.3	4.7	3.6	446.8	2.9	2.1	44.1	.8	.5	20.5	1.3	1.5	9.2	2.3	1.5	62.7	1.9	5.0	409.6	2.9	2.6	213.2	2.1	.7	12.2	3.0	1.8	31.0	6.4	.6
05	80	6	117.6	3.5	3.3	164.0	1.9	.6	222.5	3.0	3.2	87.5	1.3	3.8	34.1	1.5	3.0	61.1	2.7	5.0	114.6	2.4	2.2	110.4	2.3	.0	14.0	.9	1.4	45.7	4.1	3.6
05	85	6	108.0	9.2	4.0	57.5	2.2	.3	54.3	1.6	2.4	40.1	6.4	.8	41.6	4.5	2.7	107.5	3.9	5.7	22.8	.6	.9	21.7	.5	1.6	27.7	5.2	.7	12.7	3.5	4.7
10	85	6	760.5	.6	.5	168.4	1.3	1.6	73.1	.8	1.7	213.7	.9	8.9	466.1	4.7	3.8	319.7	3.8	3.2	82.0	3.4	2.3	25.6	4.2	.0	53.1	6.5	.9	29.4	6.3	4.6
10	90	6	137.1	3.2	1.1	39.3	.6	.0	63.7	3.0	.0	279.8	4.3	4.7	97.8	4.6	.1	202.7	4.0	2.9	70.3	4.4	.3	20.8	2.8	.0	17.3	4.1	.2	37.4	8.3	.5
10	95	6	5.0	.0	.0	2.6	.0	.0	6.9	.6	.0	10.1	1.3	.1	1.6	.0	.0	3.9	1.3	.0	12.1	7.0	.0	3.4	.4	.0	1.0	.0	.0	10.6	10.0	.0
10	100	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	.0	.0	.0	.0	.0	.0	.0
10	105	6	6.7	7.2	3.6	.0	.0	.0	3.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
15	90	6	3.9	.0	.0	5.8	.3	.0	14.7	2.9	.0	2.6	.8	1.9	5.7	3.2	.0	6.2	.2	1.6	4.5	1.0	.0	4.0	.0	.0	.8	3.8	.0	.0	.0	.0
15	95	6	29.3	.0	.1	70.4	4.0	.0	21.1	.1	.0	22.1	.4	.0	18.2	1.0	.3	30.2	1.8	.5	27.4	1.7	.0	16.7	6.0	.0	4.7	7.8	.0	14.8	6.1	.0
15	100	6	47.8	1.1	.1	42.7	1.8	.0	23.6	.7	.0	18.4	.0	.0	20.4	.8	.5	36.8	1.9	.0	66.7	3.1	.0	26.8	6.3	.2	.8	2.5	.0	11.5	.7	.0
15	105	6	28.4	3.5	.0	18.3	3.1	.0	10.6	5.0	.0	1.0	.0	.0	6.1	1.3	1.7	10.8	5.4	.0	28.0	6.0	.0	3.4	1.2	.0	.0	.0	.0	4.2	3.3	.0
15	110	6	41.6	6.9	.3	94.7	3.8	1.5	272.1	3.8	1.3	88.8	4.3	1.1	60.9	9.9	3.1	147.6	13.8	7.6	177.4	2.3	6.4	87.3	4.4	6.2	27.5	4.9	1.0	16.7	.6	.9
15	115	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	4.6	9.3	6.7	.0	.0	.0	5.0	3.2	4.2
20	105	6	56.5	.5	.3	81.0	2.0	.4	41.6	.3	.9	20.5	.3	1.8	52.3	9.4	2.3	114.4	6.5	1.9	60.5	2.6	.3	49.6	5.1	.1	19.1	.6	.8	6.4	.6	.0
20	110	6	222.4	1.3	2.9	203.9	2.2	3.6	677.4	2.0	5.6	441.7	2.6	4.7	87.5	1.7	8.0	94.2	.3	2.8	362.5	.7	6.1	429.2	3.3	2.2	18.3	.4	.7	133.8	6.7	4.9
20	115	6	1.7	.0	1.8	1.7	.4	.4	.8	.0	.0	1.6	.0	.0	.0	.0	.0	3.4	1.8	.0	23.1	5.5	.3	3.7	2.4	.0	3.5	.0	.0	.0	.0	.0
25	105	6	3.4	.1	.1	.4	.0	.0	.0	.0	.0	2.2	.3	.0	2.8	.4	.0	1.0	.0	.0	2.7	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
25	110	6	5.7	.0	.0	14.8	1.6	.1	1.7	.0	.0	4.0	.1	.0	1.9	.3	.0	3.5	.0	.5	11.1	2.7	.0	121.3	2.3	3.1	37.0	1.0	6.6	6.2	.1	.1
25	115	6	1.8	.0	.0	3.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.8	.0	.0	1.7	.0	.0	3.6	1.1	.0	1.0	.0	.0	2.6	.0	.0
30	115	6	.0	.0	.0	1.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.8	.0	.0	.6	.0	.0	.0	.0	.0	.0	.0	.0
205	80	6	1.2	.0	.0	25.8	9.0	.0	210.1	2.4	6.0	267.0	8.1	1.4	3.0	.0	.0	7.1	.0	.6	54.5	.2	10.9	115.4	2.2	5.0	5.8	.3	6.4	45.6	2.6	8.1
205	85	6	.0	.0	.0	7.2	.3	1.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.7	.0	.0	.0	.0	.0	.0	.0	.0
205	90	6	31.7	6.1	12.9	30.6	4.6	.2	3.6	.0	.1	.0	.0	.0	1.0	.5	.0	.0	.0	.0	.0	.0	.0	5.6	.0	.0	.0	.0	.0	.0	.0	.0
210	75	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	4.2	34.9	2.0	29.7	227.0	.7	24.2	110.6	6.5	36.0	2.0	.0	.0
210	80	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0	1.2	.0	.0	2.2	.0	.0	3.0	.0	.0	.0	.0	.0	.0	.0	.0

BAITBOATS

FIVE-DEGREE AREA		MONTH	1951			1952			1953			1954			1955			1956			1957			1958			1959			1960		
			SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF
00	75	7	46.7	4.3	7.3	57.1	1.0	2.2	159.4	1.7	4.4	59.1	5.5	3.1	2.0	.0	.0	92.6	1.6	6.8	50.1	.4	6.3	2.2	1.4	.0	8.3	1.8	8.5	2.4	.0	.8
00	80	7	12.9	3.8	3.5	121.2	1.1	4.4	134.3	1.0	6.8	31.3	.6	2.4	3.0	7.3	.7	34.5	2.0	6.8	57.5	.8	4.6	2.4	.0	.0	4.5	8.0	1.1	7.9	.0	8.4
00	85	7	2.3	2.2	2.2	.6	.0	.0	3.6	.0	.6	.6	.0	.0	.5	20.0	.0	.6	.0	.0	.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
00	90	7	52.2	4.2	10.3	46.2	1.9	2.3	32.6	1.5	9.0	23.6	.6	5.3	4.5	1.3	5.8	23.4	1.2	20.1	11.2	2.6	5.4	4.0	.0	7.5	.0	.0	.0	.5	.0	.0
05	75	7	12.5	1.6	.4	138.2	2.4	.8	44.8	.9	2.4	21.4	1.4	1.8	42.4	1.8	9.8	32.3	.3	2.9	29.2	.6	.2	1.2	.0	.0	10.7	1.7	1.5	5.8	.9	.3
05	80	7	16.5	2.7	.1	178.2	1.7	1.6	160.0	1.3	3.7	183.0	3.9	3.3	46.5	1.4	1.1	100.5	1.7	2.7	98.0	1.8	2.6	6.6	2.8	.0	12.1	7.6	1.3	23.5	4.7	.3
05	85	7	186.1	10.7	.2	39.9	1.8	.0	23.6	2.0	1.0	156.5	6.3	2.8	47.0	4.7	2.2	120.3	3.0	3.7	20.5	3.9	.3	3.4	1.3	1.8	2.9	6.9	.0	9.7	2.1	.8
10	85	7	336.6	7.5	.6	101.2	1.1	1.4	58.7	2.9	1.6	139.9	3.4	3.6	525.8	2.2	4.0	66.2	2.1	4.2	81.6	4.8	1.4	4.8	.5	.0	.4	2.5	.0	87.5	6.2	4.9
10	90	7	356.5	3.8	2.9	19.3	.0	.0	21.1	3.5	.5	61.0	1.6	4.6	57.2	1.4	2.6	6.1	.5	.5	22.6	1.5	.0	7.8	.4	.0	.0	.0	.0	25.7	4.6	.4
10	95	7	6.1	1.6	.5	.9	.2	.0	.0	.0	.0	.5	.0	.0	3.1	.6	1.0	2.2	3.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	3.3	.0
10	100	7	1.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
15	90	7	2.5	.0	.3	3.4	.0	.0	3.8	.0	.0	.0	.0	.0	1.0	1.0	.0	3.4	.3	5.9	8.7	1.7	.0	1.8	.0	.0	.0	.0	.0	1.2	.0	.0
15	95	7	16.0	.4	.2	90.2	6.4	.0	11.8	.1	.0	7.9	1.4	.1	11.2	1.1	.0	10.6	6.6	.0	22.9	2.9	.0	3.6	.0	.0	.0	.0	.0	3.6	2.5	.0
15	100	7	18.9	.3	.1	19.0	.1	.0	4.8	.1	.0	4.3	.5	.0	21.0	1.4	.0	10.6	1.0	.0	26.0	1.5	.0	11.2	5.4	.0	.0	.0	.0	3.6	1.1	.0
15	105	7	6.5	7.1	.0	15.1	2.9	.1	.0	.0	.0	1.5	.7	.0	1.0	9.0	.0	2.0	3.0	.0	28.2	3.1	.2	1.6	3.8	.0	.0	.0	.0	.0	.0	.0
15	110	7	16.4	5.2	.1	24.1	2.1	2.8	41.2	7.3	2.5	41.0	3.3	4.2	65.6	8.9	4.9	268.8	7.4	6.6	60.3	5.4	2.8	45.9	3.3	3.6	.0	.0	.0	2.4	.0	5.8
15	115	7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	12.0	7.3	1.8	.0	.0	.0	.0	.0	.0	.0	.0	.0
20	105	7	20.8	1.0	.5	16.5	1.6	.8	2.2	5.5	.0	6.2	1.7	.2	47.4	7.5	.5	20.0	4.3	1.7	59.4	3.1	.0	63.9	3.6	.0	.0	.0	.0	2.4	.0	.0
20	110	7	344.3	2.4	3.8	476.7	4.3	2.0	995.6	1.0	4.1	425.0	3.5	3.3	241.3	5.1	1.8	326.6	1.1	6.3	438.6	1.4	3.7	242.8	4.9	1.8	.0	.0	.0	164.3	2.8	7.4
20	115	7	26.6	2.2	1.4	46.5	5.6	1.7	39.5	2.6	1.2	26.0	5.8	.0	18.3	8.9	.0	33.1	4.3	1.6	19.7	1.3	.0	21.2	1.7	.3	1.0	.0	.0	3.3	3.3	.5
25	105	7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.8	4.4	.0	.0	.0	.0	.0	.0	.0	4.3	.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
25	110	7	46.4	.2	6.3	186.4	2.5	2.1	124.7	.6	2.1	414.2	.8	4.0	22.1	2.2	.3	25.7	.0	.7	233.7	2.0	3.5	563.7	1.0	4.7	35.3	3.5	9.8	54.2	3.1	5.0
25	115	7	12.7	.0	.9	15.2	.0	.0	5.1	.0	.0	13.4	2.5	2.0	20.4	.0	.0	19.0	.0	.0	58.7	.0	6.4	58.3	.1	3.3	48.1	.0	8.7	62.2	.8	1.7
25	120	7	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
30	115	7	2.9	.0	.0	3.8	.0	.0	.0	.0	.0	.0	.0	.0	2.2	.0	.0	2.9	.0	.0	4.7	.0	.0	1.4	.0	.0	.0	.0	.0	4.4	.0	.0
30	120	7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.6	.0	.0	.8	.0	.0	2.8	.0	.0	2.4	.0	.0
205	80	7	131.3	24.1	.9	454.5	7.9	2.8	97.9	.4	4.8	177.7	5.2	7.0	.0	.0	.0	31.4	6.1	3.3	130.5	2.4	7.3	18.0	1.9	2.4	67.6	7.8	7.3	67.3	4.4	2.5
205	85	7	.0	.0	.0	2.4	.0	.0	1.2	10.8	.0	2.8	.0	.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
205	90	7	45.3	5.6	12.7	21.8	.6	.5	7.6	2.1	2.1	16.2	12.6	.2	7.0	14.0	.0	.6	.0	.0	1.2	.0	.0	.0	.0	.0	.0	.0	.0	1.5	.0	.0
210	75	7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.8	.0	.3	89.3	1.2	11.4	286.1	2.5	7.2	2.7	.0	.0	2.3	.0	.0
210	80	7	.0	.0	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0	9.5	.0	.0	11.1	.0	1.9	2.8	.0	.0	.0	.0	.0	.0	.0	.0
215	75	7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.6	1.7	.0	3.6	.0	.0	.0	.0	.0	.0	.0	.0
220	70	7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5.8	.0	.0	.0	.0	.0	.0	.0	.0
220	75	7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	.0	.0	.0	.0	.0	.0	.0

BAITBOATS

FIVE-DEGREE AREA		MONTH	1951			1952			1953			1954			1955			1956			1957			1958			1959			1960		
			SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF
00	75	8	8.0	1.9	.0	39.5	1.9	.5	10.7	3.3	.2	43.6	1.1	5.8	14.5	.3	3.7	13.7	1.1	1.3	48.6	.3	3.4	.0	.0	.0	2.0	.0	.0	13.9	9.6	.0
00	80	E	11.8	.7	.4	51.3	1.1	1.1	21.1	.2	1.5	20.9	.7	1.9	8.7	1.1	1.0	18.6	4.0	.4	42.3	.3	1.9	3.2	.0	.6	2.9	10.2	.3	8.6	4.7	.7
00	85	8	.0	.0	.0	.0	.0	.0	10.8	.5	1.1	13.6	.0	14.8	2.2	.0	1.4	3.0	.3	1.7	24.1	1.6	15.0	1.2	10.8	1.7	.6	3.3	.0	.5	.0	.0
00	90	E	23.5	4.8	8.0	13.7	3.9	6.1	73.4	.5	7.2	10.3	.1	2.7	31.5	2.9	4.5	60.5	1.2	8.3	52.8	6.9	4.8	7.0	1.1	.1	21.7	13.9	2.3	23.4	10.7	3.8
05	75	8	2.4	.0	.0	60.9	3.4	.5	5.8	1.7	1.0	16.6	2.9	3.9	40.2	1.1	3.5	12.9	.5	1.6	20.9	.6	.2	.0	.0	.0	8.8	6.1	1.1	22.8	3.9	.9
05	80	E	54.2	3.5	.7	59.2	2.7	.2	96.7	1.2	4.1	164.7	2.4	2.5	111.0	2.2	1.4	85.2	2.2	3.3	159.5	1.6	3.1	2.0	2.5	.0	24.4	4.6	5.3	31.6	2.2	.2
05	85	E	90.4	4.3	.3	15.0	2.9	.0	57.3	5.6	1.3	82.8	2.5	2.6	140.2	2.2	1.8	75.3	1.8	2.9	44.6	1.6	1.0	5.8	2.4	.0	17.7	6.7	2.6	24.8	2.6	4.2
05	105	E	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.5	.0	.0	.0	.0	.0	.0	.0	.0
10	85	8	173.0	3.6	.1	39.0	.2	.6	72.6	4.4	3.8	383.6	.8	5.7	205.8	2.1	4.4	90.9	.7	6.0	70.7	4.6	1.6	6.0	.2	.0	3.0	2.7	.0	47.2	2.4	4.3
10	90	E	142.1	5.7	.5	16.5	.4	1.4	20.2	.6	.2	99.8	2.5	3.6	10.9	.3	1.5	19.2	3.4	3.6	12.8	.0	.4	4.0	.0	.0	.0	.0	.0	21.4	4.7	1.4
10	95	8	4.6	.0	.0	2.5	.7	.0	1.8	.0	.0	1.0	.2	.0	3.0	.8	.0	.0	.0	.0	1.7	.0	.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0
10	105	E	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	4.4	9.3	.0	.0	.0	.0	.0	.0	.0
10	110	8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0
15	90	8	2.3	.0	.0	3.0	.7	.0	3.3	.3	.0	7.4	1.4	4.5	4.0	.9	.3	5.7	2.3	13.3	2.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
15	95	E	7.0	.0	.0	18.1	2.0	.0	14.3	.0	.0	11.3	4.2	2.8	3.6	.6	1.0	9.3	.0	.0	14.9	.2	.0	3.0	.3	.0	.0	.0	.0	4.2	5.0	.0
15	100	E	13.2	1.6	.2	12.3	2.1	.0	12.4	.0	.0	4.2	.0	.0	14.8	4.3	.0	24.5	3.8	.1	18.9	.3	.0	5.0	1.2	.0	.0	.0	.0	6.5	16.9	.0
15	105	8	5.2	3.2	.1	1.3	.0	.0	1.9	.0	.0	.0	.0	.0	14.2	10.1	.0	15.9	4.6	.6	4.0	2.9	.0	3.5	.3	.0	.0	.0	.0	1.2	4.6	.0
15	110	8	5.0	10.0	1.6	21.0	2.5	2.9	75.1	4.2	.7	2.8	.2	2.0	41.5	7.9	1.8	241.8	3.6	8.8	55.7	6.2	.1	30.1	2.3	2.0	.0	.0	.0	.0	.0	.0
15	115	8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5.2	.0	.0	13.9	16.5	.2	.0	.0	.0	.0	.0	.0
20	105	8	1.7	.0	.0	11.7	1.3	.0	5.2	.2	.0	1.0	.0	.0	4.6	1.2	.0	79.7	4.2	3.3	62.2	2.1	.0	38.0	3.1	.0	1.0	7.0	.0	3.0	.5	.0
20	110	8	95.0	8.1	1.9	288.0	1.4	5.0	598.0	1.6	1.0	116.5	1.3	5.2	261.4	4.8	5.6	241.5	1.2	4.9	207.7	2.3	3.4	111.8	4.2	.0	7.1	1.1	9.5	8.1	10.3	6.2
20	115	8	32.5	.3	9.2	101.5	2.8	2.1	29.0	.7	1.3	16.9	3.2	.4	21.4	4.5	.0	64.5	7.5	.6	25.2	2.6	.0	18.3	2.6	.2	4.4	3.3	.0	.8	.0	.0
25	105	E	.0	.0	.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
25	110	E	119.4	.6	4.6	516.5	1.5	3.6	289.1	.6	1.4	449.4	.9	3.6	177.5	4.5	3.4	282.9	1.5	4.7	359.2	1.5	3.0	293.6	1.6	2.0	82.2	2.8	8.4	34.5	1.6	9.5
25	115	E	81.1	.0	6.9	48.9	.1	2.0	22.2	.1	.4	305.0	2.6	2.1	7.1	.0	.0	41.3	.4	.6	70.2	1.6	.7	342.1	.5	6.3	326.7	1.5	8.6	50.0	2.3	2.6
25	120	8	.0	.0	.0	.0	.0	.0	6.7	.0	.0	.6	.0	.0	.0	.0	.0	.0	.0	.0	.8	.0	.0	.4	.0	.0	.0	.0	.0	.0	.0	.0
30	115	8	4.3	.0	.0	6.4	.0	.0	1.2	.0	.0	.0	.0	.0	1.2	.0	.0	18.2	.0	.0	12.2	.0	1.7	75.2	.0	6.9	34.0	.0	2.4	4.9	.0	.0
30	120	8	.0	.0	.0	.0	.0	.0	4.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	6.9	.0	.0	.0	.0	.0	8.4	.0	.0
35	120	E	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.4	.0	.0	.0	.0	.0	.0	.0	.0
205	80	8	536.2	20.9	.0	664.2	6.1	1.0	72.6	.8	8.4	208.2	4.0	7.8	130.1	5.8	2.3	18.1	4.8	1.4	109.3	2.6	1.8	176.9	9.2	6.5	242.7	4.4	13.6	65.4	1.3	6.6
205	85	8	.0	.0	.0	1.8	.0	.0	11.1	2.9	6.7	.0	.0	.0	1.0	.0	.0	1.2	.0	.0	.6	.0	.0	3.6	.0	.0	3.7	15.1	.0	2.2	.0	.0
205	90	E	24.1	10.9	2.0	1.1	.0	.0	46.6	4.0	2.3	11.5	5.1	.2	5.5	.4	.0	1.8	.0	.0	6.5	10.2	.0	2.4	.0	.0	1.5	.7	.0	.0	.0	.0
210	75	E	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	48.7	3.3	4.9	237.6	2.0	13.3	.0	.0	.0	.0	.0	.0
210	80	8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5.9	3.2	1.9	.0	.0	.0	.0	.0	.0	1.2	.0	.0	1.0	.0	.0	.0	.0	.0
215	75	8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.8	.4	5.7	.0	.0	.0	.0	.0	.0
220	70	E	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	.0	.0	.0	.0	.0	.0	.0

BAITBOATS

FIVE-DEGREE AREA	MONTH	1951 SDF	1951 YF/SDF	1951 SJ/SDF	1952 SDF	1952 YF/SDF	1952 SJ/SDF	1953 SDF	1953 YF/SDF	1953 SJ/SDF	1954 SDF	1954 YF/SDF	1954 SJ/SDF	1955 SDF	1955 YF/SDF	1955 SJ/SDF	1956 SDF	1956 YF/SDF	1956 SJ/SDF	1957 SDF	1957 YF/SDF	1957 SJ/SDF	1958 SDF	1958 YF/SDF	1958 SJ/SDF	1959 SDF	1959 YF/SDF	1959 SJ/SDF	1960 SDF	1960 YF/SDF	1960 SJ/SDF
00 75	9	17.7	9.7	.6	36.3	.8	.2	39.1	1.3	5.4	15.6	1.0	1.5	2.4	.0	.1	4.7	9.4	.0	3.6	.0	.0	.0	.0	.0	6.9	.7	4.6	.0	.0	.0
00 80	9	7.1	3.2	1.1	37.8	1.0	.5	18.3	.0	2.1	6.6	.1	2.7	5.4	1.1	.0	6.4	5.5	.3	7.4	.1	2.0	.5	7.0	.0	2.6	.0	.0	.9	.6	.0
00 85	9	.0	.0	.0	16.4	.4	12.9	35.5	.2	5.5	1.2	.0	.0	.6	.0	.0	6.3	4.4	.5	22.7	.7	2.2	.0	.0	.0	.6	.0	.0	2.0	14.5	.0
00 90	9	4.0	2.5	3.4	39.1	3.1	4.9	48.0	1.2	1.3	64.7	3.0	3.3	12.0	5.4	.1	72.2	2.4	2.6	90.6	2.0	.7	.0	.0	.0	40.0	5.0	7.9	26.4	6.1	1.2
05 75	9	2.4	.0	.0	61.4	2.6	.3	4.1	.7	.1	30.3	1.8	3.8	6.5	1.3	.3	13.3	1.8	.3	27.8	3.1	.3	.0	.0	.0	4.8	2.3	.5	2.4	.1	.0
05 80	9	27.8	3.6	.4	174.5	3.4	.6	88.4	1.5	2.1	97.0	1.7	2.1	11.4	.3	.0	17.0	1.9	1.9	198.9	1.8	2.3	4.6	1.4	.0	34.9	1.0	3.7	5.9	.0	.0
05 85	9	8.5	6.5	.7	14.8	4.0	.0	83.6	2.7	1.1	95.4	2.0	4.6	9.7	1.3	3.5	42.7	3.0	1.3	68.7	3.6	.3	3.4	.4	.1	37.0	5.2	3.0	25.3	4.1	3.7
05 90	9	1.0	10.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
10 85	9	14.5	7.4	4.2	27.9	1.0	.4	92.2	.4	4.3	281.1	.5	5.9	78.6	.3	12.4	79.1	.8	4.2	88.8	3.8	1.5	3.4	.1	.0	7.2	3.8	.0	33.2	8.3	2.8
10 90	9	2.0	.0	.0	25.6	2.0	4.0	6.0	.9	.9	37.5	2.9	.3	3.0	.3	.0	60.1	3.1	6.0	10.6	.0	.0	5.2	.7	.0	2.0	4.7	.0	10.0	13.3	.2
10 95	9	1.0	.0	.0	.0	.0	.0	.0	.0	.0	2.0	1.8	.0	.0	.0	.0	1.2	1.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
10 100	9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
10 105	9	.0	.0	.0	.0	.0	.0	12.4	7.7	.0	.0	.0	.0	.0	.0	.0	1.2	10.0	.0	9.4	4.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
10 110	9	.0	.0	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
15 90	9	.0	.0	.0	1.0	.0	.0	1.0	.0	.0	9.5	2.3	.2	.0	.0	.0	7.3	5.7	7.5	1.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
15 95	9	1.0	.0	.0	15.1	1.1	.0	3.8	.0	.0	6.5	6.0	4.2	2.0	.0	.0	8.9	1.3	1.0	3.6	2.5	.0	1.8	1.1	.0	2.0	.0	.0	2.4	.8	.0
15 100	9	2.5	.0	.0	12.7	2.1	.0	5.3	.0	.0	.0	.0	.0	4.2	2.5	.7	11.3	2.2	5.2	7.0	4.0	.3	.0	.0	.0	1.5	.4	.0	3.6	.0	.0
15 105	9	1.5	.0	.0	1.2	.8	.0	2.4	.6	.0	.0	.0	.0	1.2	2.5	.0	14.0	3.6	.0	2.0	.3	.0	.0	.0	.0	1.5	8.1	.0	.0	.0	.0
15 110	9	.0	.0	.0	.0	.0	.0	45.3	2.5	.9	8.7	2.5	1.1	7.0	16.3	.1	80.1	1.4	8.0	44.4	3.6	.6	5.7	4.4	.0	.0	.0	.0	3.6	2.2	7.5
15 115	9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	3.5	16.6	.6	3.5	2.3	2.3	.0	.0	.0	.0	.0	.0
20 105	9	1.0	.0	.0	10.3	1.1	.0	7.4	.0	.0	.0	.0	.0	2.4	.8	.0	92.6	3.3	1.0	18.1	1.9	.0	.0	.0	.0	.0	.0	.0	2.4	1.3	.0
20 110	9	1.1	.0	.0	124.4	3.1	2.9	61.2	2.0	1.9	133.5	2.3	4.2	204.2	4.8	8.2	97.8	.2	6.0	80.8	2.6	3.8	2.7	.0	3.0	.8	.0	8.8	5.7	.0	.5
20 115	9	29.7	.4	8.7	30.3	1.9	3.2	51.3	1.2	3.1	46.5	4.1	2.7	1.3	.0	.0	11.2	1.0	.1	2.0	12.0	.0	10.4	1.0	.0	4.3	.0	.0	2.5	1.4	.0
25 110	9	201.0	2.0	9.7	381.5	1.9	3.9	556.3	.4	2.5	323.3	1.1	3.0	247.2	10.8	3.3	412.9	2.0	3.7	263.1	1.5	6.9	27.8	2.0	1.6	232.0	1.4	6.4	135.9	3.4	6.1
25 115	9	35.9	.1	7.5	135.6	.2	4.9	64.7	.2	1.4	5.0	1.6	1.0	4.2	.0	.0	77.8	2.3	3.0	7.6	1.1	5.8	131.3	.4	3.5	167.6	.1	7.9	16.9	.3	4.6
25 120	9	.0	.0	.0	.0	.0	.0	6.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
30 115	9	.0	.0	.0	3.0	.0	.5	2.0	.0	.0	.4	.0	.0	1.8	.0	.0	2.8	.0	.0	.0	.0	.0	338.2	.2	5.6	9.3	.0	1.7	2.0	.0	.0
30 120	9	.0	.0	.0	.0	.0	.0	10.1	.0	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	17.9	.0	.0	.0	.0	.0	.0	.0	.0
35 120	9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	8.2	.0	.0	.0	.0	.0	.0	.0	.0
205 80	9	145.8	11.0	.0	393.2	2.6	.4	350.6	3.4	4.9	25.7	3.7	2.4	340.0	5.7	11.7	34.6	5.7	.3	71.2	6.1	1.5	314.6	3.1	4.1	399.0	2.0	6.2	34.3	6.8	5.3
205 85	9	.0	.0	.0	3.5	30.6	.1	19.0	.1	3.1	.0	.0	.0	.0	.0	.0	6.9	10.1	.0	15.9	6.5	.0	.0	.0	.0	2.2	.7	.0	1.5	.0	.0
205 90	9	24.1	11.0	2.0	30.7	4.0	7.0	56.3	1.1	2.0	9.3	2.2	2.7	1.5	.0	.0	17.1	4.7	.0	8.2	1.4	.0	.0	.0	.0	.0	.0	.0	.5	.0	.0
210 75	9	.0	.0	.0	.0	.0	.0	10.0	.5	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	41.5	7.1	2.9	335.2	.3	6.4	2.8	.0	.0	.0	.0	.0
210 80	9	.0	.0	.0	.0	.0	.0	18.6	.6	2.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	10.0	.0	4.5	.0	.0	.0	.0	.0	.0
215 75	9	.0	.0	.0	.0	.0	.0	11.6	5.7	5.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.1	.0	1.7	.0	.0	.0	.0	.0	.0

BAITBOATS

FIVE-DEGREE AREA	MONTH	1951 SDF	1951 YF/SDF	1951 SJ/SDF	1952 SDF	1952 YF/SDF	1952 SJ/SDF	1953 SDF	1953 YF/SDF	1953 SJ/SDF	1954 SDF	1954 YF/SDF	1954 SJ/SDF	1955 SDF	1955 YF/SDF	1955 SJ/SDF	1956 SDF	1956 YF/SDF	1956 SJ/SDF	1957 SDF	1957 YF/SDF	1957 SJ/SDF	1958 SDF	1958 YF/SDF	1958 SJ/SDF	1959 SDF	1959 YF/SDF	1959 SJ/SDF	1960 SDF	1960 YF/SDF	1960 SJ/SDF
00 75	10	7.2	.6	.0	22.9	.2	.6	16.9	1.1	.5	15.3	.0	3.1	2.2	3.0	1.8	16.5	4.0	1.4	4.2	.0	.0	1.2	3.3	.0	7.4	2.0	1.6	3.0	2.8	16.7
00 80	10	7.7	8.6	.0	24.2	.7	.0	16.4	1.5	.7	5.1	.0	.4	1.0	3.0	.0	7.8	.8	.1	16.8	.2	5.3	1.0	.2	.0	4.1	.7	.7	1.5	2.5	2.7
00 85	10	.5	.0	.0	68.3	.4	3.4	21.9	1.3	3.9	20.6	.0	6.0	.0	.0	.0	5.2	.6	5.4	1.2	.8	5.8	4.6	12.2	.0	1.2	.0	4.2	1.5	9.3	.0
00 90	10	41.0	3.4	9.6	138.3	1.1	4.0	108.7	1.5	2.5	102.6	3.5	2.7	9.5	3.4	.8	43.7	1.7	.9	23.4	3.8	.8	27.1	4.9	1.5	55.4	6.6	5.2	5.5	4.0	.4
05 75	10	1.3	.0	.0	48.3	1.5	.0	10.2	.2	.0	4.2	.2	.0	.0	.0	.0	11.4	.8	.6	10.4	1.2	.2	.0	.0	.0	12.8	1.7	1.1	1.2	.0	.0
05 80	10	12.3	1.9	.0	217.5	2.5	1.2	142.9	1.0	1.8	73.5	.5	4.4	3.2	.0	7.2	12.7	.3	.2	42.9	1.6	.5	.0	.0	.0	20.0	.9	.5	3.2	.0	.0
05 85	10	13.6	3.7	.0	44.0	1.5	.0	37.9	.4	1.1	36.7	.2	1.2	1.2	.0	.0	20.9	1.2	2.3	31.4	2.3	.1	3.6	1.9	1.4	28.0	1.9	.0	6.2	.0	.5
05 90	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
05 95	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	2.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
05 105	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.5	.0	.0	.0	.0	.0
10 85	10	24.3	12.1	.0	43.2	1.1	.2	73.3	.3	2.4	151.8	2.2	7.4	7.7	1.2	7.5	42.8	4.0	4.1	46.9	4.0	.3	.0	.0	.0	84.3	6.1	2.9	72.0	6.7	5.4
10 90	10	3.2	.3	.9	95.6	1.7	2.6	9.2	.3	.1	9.8	.4	.0	.0	.0	.0	124.3	2.5	6.8	9.2	.1	.0	.0	.0	.0	9.1	4.8	.2	2.4	.8	.0
10 95	10	1.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	21.2	2.9	4.3	4.0	1.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
10 100	10	.0	.0	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.6	3.3	.0	1.8	3.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
10 105	10	.0	.0	.0	9.0	20.3	.0	15.7	3.9	.0	19.7	7.8	.0	.0	.0	.0	4.7	8.1	.4	.0	.0	.0	2.3	10.9	.0	.5	6.0	.0	.0	.0	.0
10 110	10	.0	.0	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
15 90	10	.0	.0	.0	4.3	1.2	.9	1.0	.0	.0	1.0	.0	.0	.0	.0	.0	8.9	.4	6.8	.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
15 95	10	.0	.0	.0	21.0	.4	.0	1.6	.0	.0	19.9	5.0	1.3	.0	.0	.0	30.9	1.7	.9	11.7	1.1	.0	.0	.0	.0	2.2	1.4	.0	.0	.0	.0
15 100	10	1.3	.0	.0	14.8	1.2	.0	1.6	.0	.0	12.8	1.6	.1	.0	.0	.0	25.8	1.8	.4	12.0	.8	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0
15 105	10	1.6	.0	.0	2.3	1.7	.0	2.6	.0	1.2	1.6	4.1	.0	.0	.0	.0	5.4	.9	.2	5.1	.2	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0
15 110	10	1.7	9.4	.0	6.5	8.0	3.7	37.9	1.4	.4	14.2	4.2	.7	62.7	8.1	3.8	73.4	3.3	3.6	20.6	1.2	.0	7.7	2.3	.6	16.4	1.2	.6	.8	5.0	5.0
15 115	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	11.4	8.7	3.9	13.7	8.1	5.0	.0	.0	.0	.0	.0	.0
20 105	10	.0	.0	.0	2.9	.0	.0	5.6	.0	.4	3.2	2.5	.0	1.2	.6	.0	131.8	2.2	4.6	27.0	7.0	.0	3.6	.3	.0	18.4	5.5	.1	7.5	.0	.0
20 110	10	17.2	13.3	2.5	29.6	1.1	2.5	10.2	.3	6.5	40.5	3.6	1.0	73.6	6.3	4.1	193.4	.4	7.1	125.0	3.8	3.7	14.9	4.8	.2	44.1	1.6	.8	33.7	4.9	1.3
20 115	10	5.9	2.7	9.2	27.0	2.6	5.7	43.3	.9	3.5	8.7	2.5	.0	6.0	1.7	.0	28.4	11.1	.1	9.0	1.0	.0	1.7	.3	.0	27.0	5.6	.0	1.7	1.8	.9
25 105	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.8	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.8	.0	.0
25 110	10	70.3	9.3	3.5	550.8	3.6	4.6	490.6	1.2	2.7	294.6	2.8	1.4	57.4	5.7	.7	196.3	2.3	3.4	218.3	1.3	6.1	96.1	2.6	2.1	175.9	.5	2.3	132.0	1.9	3.0
25 115	10	.9	.0	4.4	41.6	.7	3.7	8.0	.3	.4	2.5	.0	.0	1.4	.0	.0	1.0	.0	.0	42.6	2.2	7.3	191.4	3.5	4.6	130.6	.5	4.3	4.7	.0	.0
25 120	10	.0	.0	.0	.0	.0	.0	.8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
30 115	10	.0	.0	.0	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0	508.3	1.0	4.8	25.8	.0	3.2	.0	.0	.0
30 120	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5.9	.0	.0
205 80	10	86.7	16.5	.1	262.5	4.4	2.3	691.9	1.1	5.4	469.4	3.9	7.5	108.6	5.7	7.4	258.9	3.3	3.4	54.1	3.6	4.4	773.0	2.3	5.7	188.8	1.5	1.9	43.0	.9	4.4
205 85	10	.0	.0	.0	21.1	.4	.1	18.7	.4	.5	9.5	3.8	10.6	1.2	.8	.0	8.0	2.3	.0	.0	.0	.0	1.2	2.5	.0	1.2	.0	.0	.0	.0	.0
205 90	10	9.9	7.5	.3	132.4	1.7	3.3	62.6	4.2	.1	18.0	4.9	.5	1.2	.4	.0	20.7	6.0	.0	3.0	1.7	.0	4.3	1.2	.0	.6	.0	.0	.0	.0	.0
210 75	10	.0	.0	.0	.0	.0	.0	2.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	154.3	4.2	13.9	52.9	.0	1.5	1.7	.0	.0	.0	.0	.0
210 80	10	.0	.0	.0	.0	.0	.0	14.2	.1	.6	.5	.0	.0	.0	.0	.0	.0	.0	.0	2.6	.0	.0	14.8	.7	1.8	.0	.0	.0	.0	.0	.0
215 75	10	.0	.0	.0	.0	.0	.0	5.8	.8	.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	.0	1.8	.0	.0	.0	.0	.0
220 70	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	3.2	.0	.0	5.8	.0	.0	2.5	.0	.0
225 70	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0
230 75	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0

BAITBOATS

FIVE-DEGREE AREA		MONTH	1951			1952			1953			1954			1955			1956			1957			1958			1959			1960		
			SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF
00	75	11	.0	.0	.0	6.4	1.1	3.8	41.9	.8	3.0	1.0	.0	1.0	.0	.0	.0	6.9	4.3	6.0	10.1	3.2	5.4	1.7	.6	2.9	10.0	1.9	2.0	7.2	3.7	6.3
00	80	11	3.3	2.1	.0	16.0	.5	.7	57.7	.2	2.7	2.2	.0	.7	.0	.0	.0	6.4	.0	.0	5.1	.1	.0	5.2	4.3	1.1	6.5	1.4	.0	.8	.6	.6
00	85	11	.0	.0	.0	79.4	.7	4.4	100.6	.9	5.3	7.9	.9	3.5	.0	.0	.0	2.4	.0	.0	6.8	2.7	5.7	2.7	1.5	.0	6.1	6.8	5.4	.0	.0	.0
00	90	11	10.9	1.1	8.2	294.2	.6	5.4	258.1	1.8	2.6	26.4	3.0	4.7	16.2	4.8	3.0	19.4	3.6	2.7	23.6	6.5	1.0	45.9	5.5	1.1	83.4	4.0	2.2	.0	.0	.0
05	75	11	.8	.0	.0	12.9	.5	.0	19.8	1.6	2.2	3.0	2.7	5.7	.0	.0	.0	.0	.0	.0	2.0	.3	.0	.0	.0	.0	8.8	.0	.0	2.4	.8	.0
05	80	11	1.8	.0	.0	104.4	3.1	.9	98.8	2.5	2.2	20.7	.1	4.7	1.8	.0	.0	9.2	.0	.0	7.1	.1	.1	1.2	.0	.0	36.9	1.6	.9	4.4	.0	.0
05	[redacted]	11	7.5	3.2	.0	37.4	3.1	.6	109.7	.8	3.3	7.2	6.3	.9	.6	.0	.0	9.9	.5	3.0	11.7	10.7	.0	4.6	3.9	3.7	60.6	4.3	.3	9.5	.2	4.2
05	105	11	.0	.0	.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
10	85	11	19.4	5.5	.2	16.0	.4	.0	23.6	1.1	1.0	62.4	3.3	4.7	18.4	1.4	4.5	6.0	1.2	.1	10.0	2.8	.5	.0	.0	.0	48.7	3.1	.2	35.6	1.2	.9
10	90	11	2.4	.4	.0	16.1	.7	.0	33.6	2.8	.1	6.1	.7	.5	4.2	.4	.1	22.1	1.2	2.6	9.3	.0	.0	5.4	21.0	.0	78.5	5.8	.0	8.2	1.7	.0
10	95	11	2.6	1.6	.0	.0	.0	.0	3.6	7.5	.8	1.4	.1	.0	3.2	.6	.3	2.2	.0	.0	5.0	.8	.2	3.6	1.9	.0	2.4	1.7	.0	2.4	4.6	.0
10	100	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.8	.6	.0	.0	.0	.0	.0	.0	.0	.6	.3	.0	.0	.0	.0	.0	.0	.0	.9	.0	.0
10	105	11	8.2	5.4	.0	37.4	2.3	.0	2.0	.5	.0	4.4	3.8	.0	5.9	13.4	7.1	.0	.0	.0	51.5	10.0	.0	14.7	9.5	.0	11.4	12.4	.0	4.1	24.9	.0
15	90	11	.0	.0	.0	2.1	.0	.0	2.0	.0	.0	.4	1.8	.0	.0	.0	.0	1.2	.0	.0	2.1	.0	.0	.6	.8	.0	4.0	3.8	.0	.0	.0	.0
15	95	11	1.0	.0	.0	12.6	.0	.0	5.1	.2	.0	5.9	.9	.0	3.2	1.6	.0	6.9	.0	.0	15.0	.4	.0	3.6	5.3	.0	33.1	1.7	.0	11.9	4.2	.0
15	100	11	6.2	1.0	.0	22.4	.4	.0	29.2	.5	5.4	15.5	1.6	.0	19.4	3.6	4.5	10.5	.2	.0	97.3	2.9	.2	23.6	8.5	.0	46.3	3.3	.0	19.6	4.0	.0
15	105	11	1.8	1.7	.0	9.3	.0	.0	97.3	.2	5.6	13.4	2.5	.0	12.2	9.5	1.9	6.3	.5	.3	38.1	1.5	.0	2.3	.4	.0	7.0	.5	.0	3.0	.0	.0
15	110	11	15.9	1.7	.0	78.7	2.0	1.2	67.3	2.6	.7	51.5	1.7	.7	97.0	7.4	2.0	102.9	6.0	2.0	195.9	3.5	.4	123.4	4.6	1.5	19.8	2.0	.4	15.4	1.8	1.4
15	115	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	35.4	8.9	.4	14.4	5.3	.5	4.5	6.0	5.0	6.8	1.5	7.4
20	105	11	4.1	.7	.0	12.2	.1	.0	54.1	.1	2.5	39.3	2.7	.0	7.2	2.5	.8	126.9	.7	11.6	273.8	2.3	.0	50.2	5.0	.0	145.3	4.5	.0	2.2	.2	.0
20	110	11	29.1	2.3	.5	200.9	3.1	.3	29.3	.3	.4	14.5	.5	.0	143.7	10.5	1.3	174.0	5.0	1.4	359.3	2.3	1.2	73.7	2.8	.3	71.2	1.5	.2	17.9	.9	.0
20	115	11	7.2	2.5	4.9	17.5	1.8	3.8	11.9	.7	.8	1.7	.0	.0	2.4	1.9	.0	2.0	.0	.0	7.3	3.8	.0	10.2	.1	.0	8.7	.7	.2	1.7	2.4	.0
25	105	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.3	.2	.0	.0	.0	.0	.8	.6	.0	.0	.0	.0
25	110	11	154.4	6.2	.2	422.1	3.2	1.7	441.1	1.2	1.5	58.8	1.5	1.1	3.8	4.2	.8	50.6	4.5	2.4	126.9	2.0	2.5	401.1	3.4	1.1	236.1	2.1	1.9	301.7	3.6	2.2
25	115	11	.2	.0	.0	9.2	.0	.0	3.3	.5	.2	.0	.0	.0	1.2	.0	.0	.8	.0	.0	23.3	.3	1.5	62.4	.6	1.2	14.1	.0	1.8	.8	.0	.0
30	115	11	.0	.0	.0	.8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.6	.0	.0	1.2	.0	.0	24.7	.0	1.8	1.9	.0	.1	.0	.0	.0
30	120	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
35	120	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
205	[redacted]	11	136.4	9.7	.0	183.6	3.3	5.5	224.2	.4	3.6	564.1	4.2	9.4	70.0	3.5	9.4	493.9	1.7	5.0	378.1	3.2	3.7	353.9	4.8	4.4	301.6	1.9	5.5	3.4	.0	.9
205	85	11	.0	.0	.0	30.8	.4	5.2	41.0	.9	3.1	6.4	.0	11.9	.0	.0	.0	.0	.0	.0	.6	.0	.0	2.2	2.3	.0	29.5	3.7	8.1	.0	.0	.0
205	90	11	3.9	3.1	1.8	94.4	.4	3.6	62.4	1.1	.4	9.7	1.6	.0	.0	.0	.0	2.2	.0	.0	1.8	1.1	.0	3.5	2.0	.0	2.6	3.5	1.9	.0	.0	.0
210	75	11	.0	.0	.0	.0	.0	.0	11.7	2.6	6.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	125.9	1.7	4.9	111.0	1.1	1.6	2.9	.0	.0	.0	.0	.0
210	80	11	.0	.0	.0	.0	.0	.0	34.5	3.7	1.3	1.0	.0	.0	.0	.0	.0	1.2	.0	.0	9.0	.0	.3	5.3	2.7	3.1	.0	.0	.0	.0	.0	.0
215	75	11	.0	.0	.0	.0	.0	.0	7.0	5.0	3.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.4	.0	.0	2.9	.0	.0	1.8	.0	.0	.0	.0	.0
220	70	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.6	.0	.0	312.9	2.4	3.2	3.5	.0	.0	.0	.0	.0
220	75	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5.4	.0	.0	.6	.0	.0	.0	.0	.0
225	70	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	.0	.0	.0	.0	.0	.0	.0

BAITBOATS

FIVE-DEGREE AREA	MONTH	1951 SDF	1951 YF/SDF	1951 SJ/SDF	1952 SDF	1952 YF/SDF	1952 SJ/SDF	1953 SDF	1953 YF/SDF	1953 SJ/SDF	1954 SDF	1954 YF/SDF	1954 SJ/SDF	1955 SDF	1955 YF/SDF	1955 SJ/SDF	1956 SDF	1956 YF/SDF	1956 SJ/SDF	1957 SDF	1957 YF/SDF	1957 SJ/SDF	1958 SDF	1958 YF/SDF	1958 SJ/SDF	1959 SDF	1959 YF/SDF	1959 SJ/SDF	1960 SDF	1960 YF/SDF	1960 SJ/SDF
00	75 12	67.6	6.7	.0	15.3	1.9	2.6	10.0	.4	.6	6.1	.3	.0	8.6	.8	3.4	15.1	2.9	6.1	63.1	3.1	1.9	6.0	2.2	3.7	33.8	.1	4.6	6.0	1.0	.0
00	80 12	37.2	9.9	.0	6.2	.6	.8	14.5	1.8	1.5	2.5	.0	.0	5.9	.5	.0	4.2	.1	.1	40.5	1.4	3.6	5.2	.8	6.5	7.7	.7	.1	1.2	.0	.0
00	85 12	2.3	4.3	.0	17.5	.1	3.1	45.7	.1	2.4	43.4	.4	7.8	3.5	5.4	9.1	4.3	4.2	.5	4.7	.5	1.2	.5	.0	.0	7.9	.3	2.3	1.8	4.4	.0
00	90 12	65.0	6.1	.1	190.4	.4	4.8	194.8	1.4	2.9	45.2	1.9	5.6	12.2	7.6	6.6	12.1	5.7	1.2	71.0	2.1	2.0	18.1	1.7	4.8	62.8	3.0	3.6	14.8	1.2	.4
05	75 12	14.0	.9	.8	21.6	2.6	.0	7.5	.7	1.4	1.0	2.0	.0	1.0	1.0	.0	1.2	.0	.0	35.7	2.5	.0	6.2	4.8	.0	3.2	.0	.0	5.4	2.4	.0
05	80 12	99.1	2.8	.0	92.4	1.3	1.1	54.4	1.5	3.4	5.4	1.8	.2	9.7	1.7	.0	3.6	.0	.0	46.1	1.3	.9	1.2	.0	.0	23.0	.8	.3	9.5	2.9	.0
05	85 12	100.6	3.3	.0	141.7	2.8	.0	23.8	2.8	.0	14.6	4.9	.1	26.2	6.8	1.4	7.6	5.1	.7	58.3	2.8	.7	11.5	.8	5.4	54.1	4.1	2.6	66.2	3.7	3.1
05	90 12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
10	85 12	31.6	2.3	.0	38.7	1.1	.3	20.1	1.3	.9	93.6	1.4	10.2	70.3	.8	8.0	10.0	2.2	.0	30.6	.4	.4	5.4	1.8	.0	22.5	1.8	.0	32.6	3.2	1.5
10	90 12	12.1	.9	.0	20.8	2.3	.1	28.0	3.8	.2	29.4	7.8	1.3	33.5	2.3	1.6	3.8	.0	.0	12.2	.5	.0	23.0	2.9	.0	19.9	1.4	.0	7.1	1.5	.0
10	95 12	2.8	.0	.0	2.0	.0	3.5	9.1	17.9	5.1	1.6	.0	.0	5.7	2.3	.5	19.2	8.1	14.5	1.2	.0	.0	8.4	4.4	.0	.0	.0	.0	2.5	.1	.0
10	100 12	.0	.0	.0	2.0	.5	.3	.0	.0	.0	.0	.0	.0	2.9	4.7	.0	.0	.0	.0	.0	.0	.0	3.8	2.4	.0	1.4	.5	.0	1.7	2.1	.0
10	105 12	9.7	2.1	.0	8.2	1.3	.2	3.9	1.0	.0	1.7	6.5	.0	4.4	1.4	.0	.0	.0	.0	8.2	4.1	.0	45.8	5.8	.0	18.7	5.8	.0	4.3	6.7	.0
15	90 12	2.1	.2	.0	2.3	.0	.0	5.7	1.9	.0	.0	.0	.0	.0	.0	.0	2.6	.0	.0	1.2	.6	.0	1.2	.0	.0	1.0	.4	.0	.0	.0	.0
15	95 12	7.0	.0	.0	17.6	.0	.0	22.3	.5	.4	4.5	.2	.0	49.7	2.8	1.7	75.0	6.5	6.1	6.7	.2	.0	23.6	1.5	.0	7.0	1.4	.0	10.1	.6	.0
15	100 12	17.5	.6	.0	30.5	.1	.0	68.8	.3	1.3	19.7	2.2	.7	84.4	2.3	3.3	116.3	2.6	2.0	16.4	1.4	.1	87.7	3.4	.0	38.9	3.3	.0	21.1	2.4	.0
15	105 12	16.3	1.6	.0	15.4	.7	.0	69.5	.0	2.1	3.3	.2	.0	39.7	2.1	.1	56.0	3.4	.3	17.2	2.5	.0	18.2	1.4	.0	5.3	.1	.0	.4	.5	.0
15	110 12	9.8	2.4	.0	74.0	1.5	.3	70.3	1.5	.6	23.4	2.0	.5	95.3	6.3	2.9	156.0	4.8	.1	51.2	2.5	.2	80.3	2.4	.5	12.4	.9	1.0	11.7	1.4	.8
15	115 12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	76.8	5.8	1.8	48.5	7.3	1.2	9.0	9.9	3.4	.0	.0	.0
20	105 12	56.1	1.5	1.4	41.2	.6	.0	27.3	.1	.4	7.0	.8	.0	104.3	4.4	3.2	217.9	2.3	3.8	32.9	1.3	.0	89.1	2.0	.0	24.7	2.4	.0	15.7	1.8	.0
20	110 12	14.8	.0	.0	131.3	.7	.0	9.0	.0	.0	5.4	1.2	.0	391.2	7.0	.3	85.4	2.5	.3	111.0	2.3	.8	43.8	1.9	.2	21.6	1.9	.0	42.5	1.6	.5
20	115 12	6.1	2.9	.2	.8	.0	.0	3.2	.0	.0	.0	.0	.0	.0	.0	.0	2.8	1.8	.0	5.7	6.0	.5	2.9	.0	.0	10.7	4.8	.0	.0	.0	.0
25	105 12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0
25	110 12	75.8	3.0	.1	232.8	2.9	.4	56.1	1.1	.5	11.4	.9	.4	.6	.0	.0	17.9	2.7	.8	332.5	3.4	3.1	217.7	3.3	.4	175.4	1.9	1.4	37.0	3.3	.4
25	115 12	.0	.0	.0	1.8	.0	.0	1.7	.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.4	.0	.0	1.0	.0	.0	1.7	.0	1.5	.0	.0	.0
205	80 12	227.8	6.3	.1	187.4	.9	7.5	106.9	.2	5.9	384.7	.8	6.7	203.1	.5	16.0	313.4	.5	7.3	83.8	.7	6.0	422.1	2.0	5.7	498.4	.4	5.0	.0	.0	.0
205	85 12	1.0	.0	.0	11.7	.3	1.9	22.5	5.0	1.2	165.3	.4	11.6	1.6	.0	.0	.5	.0	.0	13.5	3.8	1.3	9.3	6.9	.2	6.4	3.4	.6	2.4	3.8	.0
205	90 12	4.3	2.2	.0	13.4	.6	1.5	38.8	2.4	.4	22.3	3.1	4.7	.0	.0	.0	2.1	.0	.0	7.7	.2	.0	1.0	.0	.0	2.9	3.1	.0	.6	.0	.0
210	75 12	.0	.0	.0	.0	.0	.0	160.3	14.9	14.4	2.2	.0	.0	1.2	.0	.0	.0	.0	.0	46.7	2.3	4.1	15.6	.7	.4	10.5	.0	.0	.0	.0	.0
210	80 12	.0	.0	.0	.6	.0	.0	9.4	2.4	.3	8.0	.3	2.4	.0	.0	.0	.0	.0	.0	2.0	.5	1.5	1.0	.0	7.0	3.6	.0	.0	.0	.0	.0
215	75 12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	11.7	.0	.0	.0	.0	.0	7.1	.0	.0	.0	.0	.0
220	70 12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	143.6	.0	12.8	25.1	1.8	19.4	10.8	.0	.0	4.0	.0	.0
220	75 12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	8.0	.0	7.9	.0	.0	.0	3.6	.0	.0	.0	.0	.0
220	80 12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
225	70 12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	96.6	1.0	8.4	.0	.0	.0	2.4	.0	.0	.0	.0	.0

PURSE SEINERS

1°-DEGREE		MONTH	1953			1954			1955			1956			1957			1958			1959			1960		
			SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF
00	75	1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	11.7	.9	.0	.0	.0	.0	.0	.0	.0
05	75	1	.0	.0	.0	.0	.0	.0	3.0	.0	.7	.0	.0	.0	.0	.0	.0	1.4	.0	1.4	.0	.0	.0	.0	.0	.0
05	80	1	15.0	1.5	.2	.0	.0	.0	6.0	.0	11.7	.0	.0	.0	1.0	.0	.0	7.6	.8	.0	.0	.0	.0	17.9	8.7	.3
05	85	1	18.0	6.9	.0	.0	.0	.0	1.0	.0	.0	1.0	.0	.0	.0	.0	.0	2.0	4.0	.0	.0	.0	.0	1.2	.0	.0
10	85	1	4.0	.0	.0	.0	.0	.0	.0	.0	.0	2.0	.0	.0	.0	.0	.0	2.8	.0	.0	.0	.0	.0	.0	.0	.0
10	90	1	2.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.5	.0	.0	1.4	.0	.0	.0	.0	.0	.0	.0	.0
10	95	1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	74.4	17.2	.0
15	90	1	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
15	95	1	4.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.0	.0	.0	.0	.0	.0	13.7	7.0	.0	252.1	13.9	.0
15	100	1	3.0	.0	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0	1.0	.0	.0	3.0	.0	.0	19.9	9.3	.0	123.1	12.9	.0
15	105	1	3.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5.3	14.2	.0
15	110	1	3.5	.0	.0	1.0	.0	.0	16.0	2.1	.0	41.9	19.0	.0	84.0	3.2	.0	70.6	4.6	.1	29.7	.7	.0	.0	.0	.0
20	105	1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.0	.0	.0	46.6	7.5	.0	24.7	5.4	.0
25	105	1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	3.0	.0	.0
A25	110	1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B25	110	1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.6	.0	.0	.0	.0	.0
25	115	1	.0	.0	.0	55.3	.0	.0	26.0	.0	.0	1.0	.0	.0	3.0	.0	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0
30	115	1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	8.0	.0	.0
205	80	1	15.0	.9	4.3	73.0	.0	14.7	234.0	.3	5.9	11.0	.7	12.6	16.0	1.0	13.8	70.7	1.1	1.2	.0	.0	.0	10.9	3.6	24.1
210	75	1	.0	.0	.0	29.1	2.9	5.5	2.7	.0	.0	.0	.0	.0	.0	.0	.0	4.1	1.0	2.7	.0	.0	.0	.0	.0	.0
210	80	1	1.4	9.3	.0	25.0	7.9	3.2	4.2	.0	2.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

PURSE SEINERS

FIVE-DEGREE		MONTH	1953			1954			1955			1956			1957			1958			1959			1960		
			SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF
00	75	2	4.7	.0	.0	.0	.0	.0	7.0	.3	.3	.0	.0	.0	2.0	.0	.0	3.0	.0	.0	.0	.0	.0	.0	.0	.0
00	80	2	2.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	3.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
05	75	2	9.4	.0	.0	7.0	18.6	.0	4.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
05	80	2	28.2	.8	.4	.0	.0	.0	34.5	3.8	1.2	1.0	.0	.0	5.7	.0	.0	.0	.0	.0	.0	.0	.0	11.2	31.7	.0
05	85	2	15.5	.9	.0	.0	.0	.0	38.0	3.2	6.3	.0	.0	.0	4.5	.0	.0	.0	.0	.0	.0	.0	.0	6.7	36.4	.0
10	85	2	12.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	3.5	.0	.0	.0	.0	.0	.0	.0	.0	.6	.0	.0
10	90	2	4.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
10	95	2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	4.3	11.9	.0
15	85	2	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
15	90	2	3.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
15	95	2	9.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5.3	7.4	.0	.0	.0	.0	175.7	14.3	.0
15	100	2	6.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	38.7	3.5	.0	11.8	.4	.0	378.3	11.3	.0
15	105	2	2.5	.0	.0	.0	.0	.0	.0	.0	.0	2.0	.0	.0	.0	.0	.0	1.0	.0	.0	.8	.0	.0	13.2	4.9	.0
15	110	2	21.0	.7	.0	77.0	1.9	.1	49.6	5.8	.0	311.8	9.1	.0	506.6	3.9	.2	210.1	4.2	.7	14.0	3.6	.0	.0	.0	.0
20	105	2	5.0	.0	.0	81.3	.8	.0	3.9	.0	.0	71.2	5.7	.6	12.0	3.8	.0	38.5	3.3	.0	203.5	14.0	.0	74.0	8.9	.0
20	110	2	1.0	.0	.0	.0	.0	.0	.0	.0	.0	2.0	.0	.0	.0	.0	.0	3.0	3.0	.0	1.0	.0	.0	.0	.0	.0
25	105	2	.0	.0	.0	3.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	4.1	.0	.0	45.5	19.9	.0	.0	.0	.0
A25	110	2	.0	.0	.0	2.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
825	110	2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
25	115	2	.0	.0	.0	17.0	.0	.0	3.0	.0	.0	.0	.0	.0	3.0	.0	.0	61.3	.0	.0	8.2	.0	.0	.0	.0	.0
205	80	2	35.3	2.1	1.9	112.7	.6	18.8	198.6	.3	6.9	54.4	.7	13.4	25.5	.3	.8	42.0	.4	1.3	.0	.0	.0	9.5	6.6	10.1
210	80	2	12.3	2.1	5.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.4	.0	.0
220	70	2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	13.2	13.1	10.9
225	70	2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5.4	22.6	.2

PURSE SEINERS

FIVE-DEGREE		MONTH	1953			1954			1955			1956			1957			1958			1959			1960		
			SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF
00	75	3	59.6	.7	2.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
00	80	3	8.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
05	75	3	4.4	.0	.0	.0	.0	.0	4.0	5.5	.0	5.0	.0	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
05	80	3	22.9	.0	.0	.0	.0	.0	36.4	1.3	.4	2.0	.0	.0	.0	.0	.0	2.0	.0	.0	.0	.0	.0	13.1	17.8	.0
05	85	3	27.5	1.6	.0	.0	.0	.0	81.4	1.7	.5	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
10	85	3	8.5	.0	.0	.0	.0	.0	9.9	.8	.0	1.0	.0	.0	.5	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	.0
10	90	3	6.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
10	95	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	21.8	15.5	.0
15	90	3	2.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
15	95	3	4.5	.0	.0	1.0	.0	.0	2.0	.0	.0	.0	.0	.0	2.5	.0	.0	1.0	.0	.0	.0	.0	.0	35.3	9.8	.0
15	100	3	7.0	2.5	2.5	10.0	3.3	.0	3.9	1.3	.0	1.0	.0	.0	17.5	7.7	.0	44.0	9.7	.0	2.6	13.5	.0	203.9	7.7	.0
15	105	3	1.5	.0	.0	3.9	1.5	.0	1.4	.0	.0	8.7	2.5	1.7	.5	.0	.0	.0	.0	.0	.0	.0	.0	5.9	5.6	.0
15	110	3	31.0	5.3	.4	50.3	1.1	.0	154.1	2.8	.6	399.1	8.3	.3	266.6	3.6	1.0	44.6	4.8	.0	2.4	.0	.0	4.9	.0	.0
20	105	3	286.6	5.4	.3	857.1	1.1	.0	232.9	3.2	.1	242.7	6.9	1.6	299.7	6.1	.8	403.4	6.7	.0	462.6	14.7	.1	454.6	9.4	.0
20	110	3	.0	.0	.0	3.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	3.3	.0	.0	1.0	.0	.0	161.6	15.3	.0
20	115	3	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
25	105	3	2.6	19.2	.0	9.3	3.9	.0	2.9	.0	.0	.0	.0	.0	.0	.0	.0	47.9	6.7	.0	1.0	.0	.0	1.8	.6	.0
A25	110	3	4.0	.0	.0	4.0	.0	.0	.0	.0	.0	.0	.0	.0	2.4	.0	.0	.0	.0	.0	*	*	*	1.7	.0	.0
B25	110	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0
25	115	3	1.0	.0	.0	2.0	.0	.0	6.0	.0	.0	.0	.0	.0	1.0	.0	.0	2.4	.0	.0	4.2	.0	.0	2.0	.0	.0
205	80	3	74.9	.3	6.8	43.8	.0	17.6	41.7	2.6	15.5	12.0	.3	1.0	.0	.0	.0	3.0	.0	.0	.0	.0	.0	4.0	.0	30.0
210	75	3	.0	.0	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
210	80	3	.0	.0	.0	2.7	.0	.0	16.8	.0	2.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
220	70	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	4.0	43.0	.0

PURSE SEINERS

FIVE-DEGREE		MONTH	1953			1954			1955			1956			1957			1958			1959			1960		
			SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF
00	75	4	5.2	.0	.0	8.3	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
00	80	4	.7	.0	.0	2.8	5.4	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	7.7	4.8	27.0
05	75	4	10.6	.0	.0	31.4	3.4	.0	.0	.0	.0	2.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
05	80	4	5.5	.2	.2	39.8	1.1	.3	.0	.0	.0	4.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	43.4	18.2	.0
05	85	4	1.0	.0	.0	23.5	.7	1.5	.0	.0	.0	14.2	6.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	19.6	24.7	.0
10	85	4	5.4	6.1	.2	14.5	.0	7.4	8.7	.2	.0	21.6	1.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	7.0	35.0	1.0
10	90	4	3.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	72.9	23.9	.0
10	95	4	1.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	7.2	12.2	.0
15	90	4	1.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.6	.0	.0
15	95	4	1.9	.0	.0	13.8	.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	87.8	12.8	.0
15	100	4	3.9	.0	.0	96.1	1.1	.8	.0	.0	.0	1.0	.0	.0	14.0	10.1	.0	.0	.0	.0	90.7	7.7	.0	90.1	9.2	.0
15	105	4	.5	.0	.0	4.0	1.2	1.2	.0	.0	.0	1.0	.0	.0	3.0	.0	.0	.0	.0	.0	7.5	1.2	.0	14.7	11.8	.0
15	110	4	23.5	2.9	1.4	74.4	2.5	.4	119.3	4.4	1.0	209.4	4.5	.0	167.5	5.4	.0	6.0	6.3	.0	1.0	.0	.0	.0	.0	.0
20	105	4	365.6	4.1	.7	417.5	1.3	.0	390.0	6.9	.0	349.1	4.6	1.1	436.7	4.4	.0	313.3	8.3	.0	481.5	6.8	.1	513.9	4.1	.0
20	110	4	1.8	.0	.0	.0	.0	.0	.0	.0	.0	2.5	.0	.0	1.0	.0	.0	2.0	.0	.0	74.7	4.8	.0	91.8	6.3	.0
20	115	4	.0	.0	.0	.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
25	105	4	20.2	5.5	.0	5.5	.0	.0	15.6	2.4	.0	.0	.0	.0	2.0	.0	.0	201.1	10.4	.0	.5	.0	.0	3.2	.0	.0
A25	110	4	150.1	1.6	.0	24.2	.1	.0	6.9	7.2	.0	1.8	.0	.0	7.8	.0	.0	21.5	5.3	.0	2.5	.0	.0	30.2	3.7	.0
825	110	4	.0	.0	.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5.9	.0	.0	3.7	.0	.0
25	115	4	1.0	.0	.0	16.9	.0	.0	1.0	.0	.0	1.0	.0	.0	1.0	.0	.0	.0	.0	.0	1.0	.0	.0	3.7	.0	.0
30	115	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	6.0	.0	.0	8.5	.0	.0	1.0	.0	.0
205	80	4	30.8	.9	4.8	141.3	4.3	1.6	26.9	.7	8.9	.0	.0	.0	.0	.0	.0	15.1	8.8	27.5	19.5	5.1	19.8	16.5	.0	43.4
210	75	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.7	.0	18.1
210	80	4	13.7	4.7	1.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

PURSE SEINERS

FIVE-DEGREE		MONTH	1953			1954			1955			1956			1957			1958			1959			1960		
			SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF
00	75	5	4.8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
00	80	5	.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
05	75	5	4.8	.0	.0	20.2	3.0	1.4	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
05	80	5	2.1	.0	.0	2.4	.0	.0	1.0	.0	.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	20.3	21.7	.0
05	85	5	.0	.0	.0	.0	.0	.0	1.0	.0	.0	26.7	6.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.4	20.8	.0
05	90	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	58.3	.0
10	85	5	.0	.0	.0	234.3	.1	7.2	2.0	.0	.0	6.9	2.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	19.4	26.9	.0
10	90	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	75.7	26.8	.0
10	95	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.4	.0	.0
10	100	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.1	.0	.0
15	95	5	.0	.0	.0	7.8	1.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	38.5	22.9	.0
15	100	5	.7	.0	.0	9.3	.0	.0	.0	.0	.0	2.0	.0	.0	144.5	7.4	.0	.0	.0	.0	13.2	18.9	.0	325.1	18.0	.0
15	105	5	.7	.0	.0	.5	.0	.0	.0	.0	.0	.0	.0	.0	15.3	6.5	.0	.0	.0	.0	3.7	21.6	.0	9.9	6.7	.0
15	110	5	60.8	4.0	.2	85.8	1.3	3.0	48.1	5.4	.4	100.1	4.2	.0	75.2	7.8	.2	.0	.0	.0	.0	.0	.0	1.0	.0	.0
20	105	5	277.4	2.3	.1	359.0	1.8	.2	796.0	4.9	.0	318.3	4.0	.1	343.1	8.9	.0	74.6	4.4	.0	109.6	5.8	.0	262.7	6.7	.0
20	110	5	168.2	3.2	.3	15.8	1.0	.0	.0	.0	.0	31.1	.0	.0	1.0	.0	.0	6.3	.2	.0	130.6	10.7	.0	2.8	1.8	.0
20	115	5	3.0	10.0	1.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
25	105	5	17.3	1.0	.0	1.5	.0	.0	10.8	4.4	.0	.0	.0	.0	.0	.0	.0	158.4	8.5	.0	.0	.0	.0	.0	.0	.0
A25	110	5	167.2	.6	.0	11.0	.0	.0	3.0	1.7	.0	4.5	.0	.0	6.4	.0	.0	339.2	7.1	.0	.0	.0	.0	.0	.0	.0
B25	110	5	6.0	.0	.0	3.0	.0	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0	2.0	21.5	.0	4.4	.0	.0	4.9	.0	.0
25	115	5	.0	.0	.0	56.9	.0	.0	1.0	.0	.0	.0	.0	.0	1.0	.0	.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0
30	115	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	3.5	.0	.0	4.0	.0	.0
205	80	5	22.0	.0	4.8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	11.0	4.9	.3	6.5	.0	31.5	27.6	1.5	16.3
210	75	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.6	.0	.0	2.4	.0	8.8
210	80	5	5.5	.0	6.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

PURSE SEINERS

FIVE-DEGREE		MONTH	1953			1954			1955			1956			1957			1958			1959			1960		
			SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF
05	80	6	2.8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	73.0	10.3	.0
05	85	6	4.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	26.7	7.2	.8
10	85	6	10.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	56.9	13.2	.4
10	90	6	1.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	106.7	10.2	.0
10	95	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	6.0	8.7	.0
15	90	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	6.0	.0	.0
15	95	6	2.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	125.4	14.9	.0
15	100	6	2.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0	156.9	3.0	.0
15	105	6	1.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	18.0	2.3	.0
15	110	6	22.0	.1	.1	24.9	.3	.5	21.3	1.2	.2	11.7	19.2	.0	3.0	1.0	4.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20	105	6	277.2	2.4	.1	234.0	3.0	.2	81.4	1.8	.0	215.7	2.8	.0	30.0	2.6	.0	58.9	3.8	.0	.0	.0	.0	145.3	3.8	.0
20	110	6	227.4	7.7	.4	191.4	5.3	1.0	11.3	1.7	2.7	332.1	6.6	.7	38.0	.4	6.6	78.0	6.4	1.7	.0	.0	.0	78.3	4.8	1.6
20	115	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.0	.0	.0	.0	.0	.0	.0	.0	.0
25	105	6	.9	.0	.0	.0	.0	.0	94.1	5.1	.0	1.5	.0	.0	1.9	4.2	.0	75.3	9.4	.0	.0	.0	.0	.0	.0	.0
A25	110	6	1.0	.0	.0	.0	.0	.0	137.7	4.6	.0	12.0	.0	.0	.0	.0	.0	59.6	2.5	.0	.0	.0	.0	32.2	7.6	.0
B25	110	6	10.2	.0	.0	9.3	.0	.0	.0	.0	.0	10.2	.0	.0	125.5	.1	.0	131.1	7.8	2.7	.0	.0	.0	120.1	.0	4.9
25	115	6	2.8	.0	.0	.0	.0	.0	.0	.0	.0	9.9	.0	.0	2.9	.0	.0	4.0	.0	.0	.0	.0	.0	49.9	.1	.4
30	115	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0	38.2	.0	.0
205	80	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	13.2	7.6	17.4	33.1	.6	17.1

PURSE SEINERS

FIVE-DEGREE		MONTH	1953			1954			1955			1956			1957			1958			1959			1960		
			SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF
05	80	7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	3.9	.0	.0
10	85	7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	34.1	3.5	7.8
10	90	7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	59.5	5.2	3.7
15	90	7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.0	.0	.0
15	95	7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	14.1	.0	.0
15	100	7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	18.2	.8	.0
15	105	7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	8.2	.0	.0
15	110	7	4.3	.0	.0	3.0	2.0	.0	.0	.0	.0	2.0	12.5	.0	2.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20	105	7	9.0	5.4	3.4	.0	.0	.0	100.3	6.0	.2	85.8	4.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	22.5	.0	.0
20	110	7	158.4	7.9	1.2	30.8	.5	4.1	37.9	2.2	.1	135.9	4.6	.6	47.4	4.6	1.5	1.0	.0	.0	5.2	21.2	.0	347.9	4.5	1.8
20	115	7	2.0	15.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	4.0	8.8	.0	.0	.0	.0	.0	.0	.0	5.9	4.2	3.4
A25	110	7	.5	44.0	.0	.0	.0	.0	.0	.0	.0	2.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B25	110	7	240.2	1.6	.7	123.8	3.8	.5	34.7	.0	.0	56.6	.0	.4	179.3	3.5	2.3	57.5	8.7	.7	340.9	2.6	10.3	211.7	2.7	2.3
25	115	7	8.0	.0	.0	1.0	.0	.0	.0	.0	.0	44.7	.0	.0	38.1	.0	1.2	24.8	.0	.6	65.0	2.7	4.6	183.4	.4	1.1
30	115	7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	34.8	.0	.0	2.9	.0	.0	9.2	.0	2.7	70.9	.0	.0
205	80	7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	16.5	.0	30.6	23.0	1.9	38.0	17.6	.0	23.7

PURSE SEINERS

FIVE-DEGREE		MONTH	1953			1954			1955			1956			1957			1958			1959			1960		
			SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF
05	80	8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	12.0	2.7	.0	27.3	13.5	.3
05	85	8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	4.8	6.3	.0	8.1	9.6	.0
10	85	8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	.0	142.1	10.0	.5
10	90	8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.4	11.7	4.2	227.3	12.2	.5
15	90	8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.7	.0	.0
15	95	8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	19.3	.2	.0
15	100	8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	.0	20.9	.1	.0
15	105	8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.7	8.1	.0
15	110	8	2.4	.0	.0	.0	.0	.0	.0	.0	.0	11.0	12.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20	105	8	.0	.0	.0	.0	.0	.0	.0	.0	.0	3.0	.0	.0	.0	.0	.0	.0	.0	.0	7.2	.0	.0	20.8	.0	.0
20	110	8	200.6	5.0	.6	48.5	5.2	.7	.0	.0	.0	48.4	7.4	1.0	1.5	13.3	.0	.0	.0	.0	5.2	.0	.0	67.3	4.5	2.4
20	115	8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0
A25	110	8	1.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B25	110	8	111.8	1.4	.4	131.3	.5	2.3	54.9	5.6	1.8	18.2	.0	.2	4.5	.9	.0	114.9	11.5	.6	213.5	2.1	4.5	157.0	1.9	4.4
25	115	8	2.3	.0	.0	12.4	2.2	.2	.9	.0	.0	44.7	.0	.0	.0	.0	.0	20.2	.7	8.2	111.7	1.9	3.9	53.7	1.5	1.9
30	115	8	.0	.0	.0	35.1	.0	.0	.0	.0	.0	4.4	.0	.0	19.9	.0	1.5	26.7	.0	.0	57.1	.0	.8	233.9	.0	.0
30	120	8	.0	.0	.0	4.8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0	1.2	.0	.0
205	80	8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	23.3	7.5	14.4	42.0	8.5	15.6	6.8	14.7	22.1

PURSE SEINERS

FIVE-DEGREE		MONTH	1953			1954			1955			1956			1957			1958			1959			1960		
			SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF
00	75	9	2.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
05	75	9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.4	.0	.0	.0	.0	.0
05	80	9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	11.0	.0	.0
05	85	9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	10.7	3.7	1.3
10	85	9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	192.9	12.1	.8
10	90	9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	77.0	11.9	.4
15	90	9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.4	.0	.0
15	95	9	1.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	13.5	6.0	.0
15	100	9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	8.4	.0	.0	10.9	2.8	.0
15	105	9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.7	.0	.0
15	110	9	.0	.0	.0	.0	.0	.0	.0	.0	.0	5.0	1.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
20	105	9	.0	.0	.0	.0	.0	.0	.0	.0	.0	5.4	.0	.0	.0	.0	.0	.0	.0	.0	14.0	.0	.0	6.7	.0	.0
20	110	9	8.6	7.6	2.0	4.0	.0	6.3	.0	.0	.0	3.4	.0	.0	.0	.0	.0	.0	.0	.0	3.8	.0	.0	14.6	1.0	.3
20	115	9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.3	.0	.0	.0	.0	.0
A25	110	9	.0	.0	.0	.0	.0	.0	.0	.0	.0	10.9	.0	1.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B25	110	9	30.2	1.9	1.7	148.3	1.8	2.6	.0	.0	.0	28.4	.3	.5	.0	.0	.0	.0	.0	.0	98.6	3.6	1.7	94.0	4.9	4.0
25	115	9	12.6	.0	.0	10.0	.0	.0	.0	.0	.0	12.0	2.9	.1	.0	.0	.0	.0	.0	.0	12.4	.0	4.3	44.9	2.6	6.1
30	115	9	.0	.0	.0	6.8	.0	.0	.0	.0	.0	6.4	.0	.0	.0	.0	.0	5.4	.0	4.4	1.3	.0	.0	3.0	.0	.0
205	80	9	24.0	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	20.6	2.3	13.8	57.8	5.5	15.3	.0	.0	.0
210	75	9	1.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
210	80	9	2.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

PURSE SEINERS

FIVE-DEGREE	MONTH	1953 SDF	1953 YF/SDF	1953 SJ/SDF	1954 SDF	1954 YF/SDF	1954 SJ/SDF	1955 SDF	1955 YF/SDF	1955 SJ/SDF	1956 SDF	1956 YF/SDF	1956 SJ/SDF	1957 SDF	1957 YF/SDF	1957 SJ/SDF	1958 SDF	1958 YF/SDF	1958 SJ/SDF	1959 SDF	1959 YF/SDF	1959 SJ/SDF	1960 SDF	1960 YF/SDF	1960 SJ/SDF
00 90	10	1.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
05 75	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.5	16.0	.0
05 80	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	3.3	12.7	.0	22.6	4.1	.0
05 85	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	59.8	5.4	.7	35.7	5.9	.8
10 85	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	15.8	1.5	.8	227.5	7.7	.2
10 90	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	10.9	10.4	.0	88.1	4.7	.0
10 95	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	3.7	.0	.0
15 90	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0
15 95	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	3.1	.0	.0	45.7	2.0	.0
15 100	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.3	.0	.0	59.1	2.7	.0
15 105	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	.0	7.2	.0	.0
15 110	10	.0	.0	.0	.0	.0	.0	22.0	5.5	.1	127.6	2.4	.0	.0	.0	.0	.0	.0	.0	8.1	.5	.0	1.0	.0	.0
20 105	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	11.4	.6	.1	.0	.0	.0	.0	.0	.0	8.7	2.4	.0	18.5	.0	.0
20 110	10	.0	.0	.0	.0	.0	.0	6.9	2.2	.1	15.5	.0	.2	.0	.0	.0	.0	.0	.0	91.9	5.4	.0	8.8	.0	.0
20 115	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0
A25 110	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	4.8	.0	.0	.0	.0	.0	.0	.0	.0	1.3	.0	.0	.0	.0	.0
B25 110	10	.0	.0	.0	7.0	.0	.0	.0	.0	.0	23.3	.0	.1	.0	.0	.0	5.5	.0	.0	131.2	3.6	.6	30.2	2.2	.7
25 115	10	.0	.0	.0	5.0	.0	.0	9.6	.0	.0	8.7	.0	.0	.0	.0	.0	2.7	.0	.0	14.1	.0	.0	.0	.0	.0
30 115	10	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.4	.0	.0	.0	.0	.0	80.3	.6	5.5	.0	.0	.0	1.4	.0	.0
205 80	10	38.0	.0	4.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	28.5	6.3	3.2	.0	.0	.0
205 85	10	6.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
205 90	10	17.1	2.1	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
210 80	10	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

PURSE SEINERS

FIVE-DEGREE	MONTH	1953			1954			1955			1956			1957			1958			1959			1960		
		SDF	YF/ SDF	SJ/ SDF	SDF	YF/ SDF	SJ/ SDF	SDF	YF/ SDF	SJ/ SDF	SDF	YF/ SDF	SJ/ SDF	SDF	YF/ SDF	SJ/ SDF	SDF	YF/ SDF	SJ/ SDF	SDF	YF/ SDF	SJ/ SDF	SDF	YF/ SDF	SJ/ SDF
00 75	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	2.5
05 75	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	.0	15.3	9.3	.2
05 80	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0	1.4	.0	.0	.0	.0	.0	15.4	17.7	.0	29.6	4.8	.0
05 85	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	30.8	15.4	.0	39.1	3.1	.1
10 85	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	6.0	3.3	.0	.0	.0	.0	.0	.0	.0	8.6	3.6	.0	371.6	6.1	1.5
10 90	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	14.7	11.2	.0	395.9	8.0	.7
10 95	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	10.0	.0	21.1	6.9	.0
15 90	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	9.8	.0	.0
15 95	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	139.5	13.3	.0	330.4	8.0	.0
15 100	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	12.8	.0	.0	62.3	2.3	.0
15 105	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.3	.0	.0	6.6	.0	.0
15 110	11	.0	.0	.0	.0	.0	.0	24.1	17.4	.4	169.5	3.3	.0	85.3	7.7	.0	43.8	7.9	1.3	.0	.0	.0	.0	.0	.0
20 105	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	13.0	.4	.0	17.0	.0	.0	.0	.0	.0	70.8	2.0	.0	11.6	.0	.0
20 110	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	6.8	.1	.1	1.0	.0	.0	2.8	.0	.0	112.1	2.7	.0	7.3	.0	.0
20 115	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.4	.0	.0	.0	.0	.0	.0	.0	.0
25 105	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0
A25 110	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	3.4	.8	.0	.0	.0	.0
825 110	11	.0	.0	.0	8.0	13.6	1.0	.0	.0	.0	1.0	.0	.0	6.1	1.0	.2	23.3	2.6	.3	62.7	4.2	.0	61.0	6.7	.8
25 115	11	.0	.0	.0	13.0	.0	.0	.0	.0	.0	8.0	.0	.0	5.0	.0	.0	4.8	.0	.3	4.6	.0	1.5	4.0	.0	.0
30 115	11	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.3	.0	.0	2.0	.0	.0
205 80	11	20.7	.0	3.3	12.0	.0	9.0	.0	.0	.0	43.0	.0	5.7	18.9	.0	.0	.0	.0	.0	18.2	.0	15.9	.0	.0	.0
210 75	11	14.0	7.0	4.5	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
210 80	11	18.1	4.3	2.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

PURSE SEINERS

FIVE-DEGREE	MONTH	1953			1954			1955			1956			1957			1958			1959			1960		
		SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF	SDF	YF/SDF	SJ/SDF
00 75	12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	9.5	.1	.9	.0	.0	.0	.0	.0	.0	.0	.0	.0
05 75	12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.2	.0	.0	.0	.0	.0
05 80	12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	8.4	7.9	.4	16.3	4.8	.0
05 85	12	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0	12.6	11.8	.2	12.1	11.0	.0
10 85	12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.6	16.7	.0	29.6	1.6	.0
10 90	12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	47.6	5.4	.0
10 95	12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	155.3	12.1	.0
15 90	12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.9	2.6	.0
15 95	12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	51.4	11.4	.0	462.7	11.5	.0
15 100	12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	66.9	8.1	.0	146.7	6.2	.0
15 105	12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.9	.0	.0
15 110	12	.0	.0	.0	.0	.0	.0	.0	.0	.0	62.1	4.7	.0	140.1	2.2	.0	33.3	3.6	2.2	1.0	.0	.0	1.0	.0	.0
20 105	12	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.0	.0	.0	5.0	.0	.0	.0	.0	.0	13.2	1.4	.0	6.6	.0	.0
20 110	12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.0	.0	.0	.0	.0	.0	1.9	.0	.0	.0	.0	.0
A25 110	12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B25 110	12	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	3.0	.2	.0	.0	.0	.0	2.5	10.0	.0	7.8	1.9	.0
25 115	12	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.0	.0	.0	.0	.0	.0	2.0	.0	.0	6.5	.0	.0	.0	.0	.0
205 80	12	.0	.0	.0	29.0	.1	12.6	.0	.0	.0	9.0	.0	2.5	43.5	.1	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0
205 85	12	.0	.0	.0	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
205 90	12	.0	.0	.0	4.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
210 75	12	10.4	9.8	2.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

DISTRIBUCION MENSUAL DE LA PESCA POR UNIDAD DE ESFUERZO Y DEL ESFUERZO EN LA PESCA DE ATUN DEL OCEANO PACIFICO ORIENTAL TROPICAL DURANTE EL PERIODO 1951-1960

por

John Wilson Martin[1]

INTRODUCCION

La Comisíon Interamericana del Atún Tropical ha recolectado sistemá-camente, desde 1951, los datos de los cuadernos de bitácora que registran captura y el esfuerzo de los barcos de carnada y de los barcos rederos edicados a la pesca de los atunes aleta amarilla *(Neothunnus macrop-rus)* y barrilete *(Katsuwonus pelamis)* en el Océano Pacífico Oriental ropical, con el propósito principal de vigilar los cambios en el esfuerzo de esca, en la abundancia y en el rendimiento de estas especies. Schaefer 1953), Shimada y Schaefer (1956) y Shimada (1958) han descrito detalla-amente los métodos de recolección de dichos datos y su tabulación y nálisis. Muchos de los datos fundamentales han sido publicados en la serie e *Boletines* de la Comisión por Shimada y Schaefer (1956), Alverson 1959 y 1960), Griffiths (1960), y Calkins (1961).

La comparación de los factores ambientales físicos y biológicos que fectan la agrupación del atún, con el éxito obtenido en la pesca por las otas comerciales, requiere que los datos sobre la captura y el esfuerzo an examinados con mayor detalle de lo que han sido presentados en estas ublicaciones. En consecuencia, el Laboratorio Biológico del Buró de Pes-uerías Comerciales de los Estados Unidos, situado en San Diego, a fin de enar los requisitos de su programa de investigación sobre las causas de s variaciones en la abundancia del atún, hizo arreglos con la Comisión del tún para sumarizar esos datos sobre la captura y el esfuerzo por meses, or áreas de un grado, por clases de tamaño de las embarcaciones de pesca urante los años 1951-1960 en lo que concierne a los barcos de carnada y urante el período 1953-1960 en lo que respecta a los barcos rederos. El resente trabajo describe la técnica empleada en la sumarización de dichos atos mediante métodos automáticos de manejo de datos. También se da quí la información sobre la captura y el esfuerzo por meses, por áreas de nco grados y ciertas combinaciones de áreas de cinco grados para el uso e los pescadores, del personal de la industria y de las oficinas de investi-ación. Por falta de espacio y otras razones, las tabulaciones de las áreas e un grado no han sido incluídos en este trabajo, pero están a la disposi-ón de quien tenga interés en los laboratorios de la Comisión del Atún del Buró.

[1] Del Laboratorio Biológico del Buró de Pesquerías Comerciales de los Estados Unidos, San Diego, California

Un sistema de computación 650 de la "International Business Machines" (IBM) que puso a la disposición del Buró la General Dynamics-Convair, San Diego, ha sido usado para la estandarización del esfuerzo de pesca, para la computación de la abundancia aparente de cada especie por estratos de tiempo y área. El autor preparó instrucciones especiales sobre la computación para el rápido manejo de esos datos básicos.

RECONOCIMIENTO

Los datos fundamentales fueron puestos a disposición del Laboratorio Biológico del Buró de Pesquerías Comerciales de los Estados Unidos en San Diego, por el Dr. M. B. Schaefer, Director de Investigaciones de la Comisión Interamericana del Atún Tropical. Los señores D. L. Greenland y A. B. Chapman, del personal del Buró, ayudaron a reunir los datos para los gráficos y a comprobar la exactitud de los datos presentados. El señor Keith Quigley de la Comisión del Atún, preparó las figuras. El señor G. C. Broadhead, del personal de la Comisión del Atún proveyó la información que facilitó la tabulación de los datos y también revisó el manuscrito con sentido crítico. El autor agradece la cooperación de las personas aquí citadas.

METODOS

Los datos básicos utilizados en este informe son el resultado del sistema de registro en los cuadernos de bitácora establecido por la Comisión del Atún en 1951 para vigilar corrientemente las actividades de las flotas que pescan atún tropical. Los métodos empleados dentro de este sistema han sido detallados por Schaefer (1953) y Shimada (1958), y sólo se discutirán superficialmente. Los datos con respecto al esfuerzo de pesca y a las capturas resultantes de atún aleta amarilla y barrilete se toman de los records de los viajes que contienen los cuadernos de bitácora llevados por los capitanes de los barcos de carnada y rederos que pescan en el Océano Pacífico Oriental Tropical.

Corrientemente, miembros del personal de la Comisión del Atún transcriben, analizan y tabulan estos datos. Para facilitar el manejo de esta gran cantidad de información, los datos tabulados se registran, al final del año, en tarjetas perforadas, con un formato que indica el área en que se ha pescado, por rectángulos de un grado, el mes, la clase de tamaño y tipo del barco, los diás en que se ha pescado, y la captura de atún aleta amarilla y barrilete. Estas tarjetas perforadas fueron prestadas al Buró de Pesquerías Comerciales de los Estados Unidos y proveyeron la información necesaria para preparar este informe.

En la Figura 1 se presentan las áreas estadísticas de la Comisión y los números de código que les han sido asignados. Las divisiones más pequeñas son las áreas de un grado que, combinadas, forman las áreas de cinco grados. Las áreas al norte del ecuador están identificadas en código por siete dígitos. Un prefijo adicional, el dígito "2", se usa para denotar las áreas al sur del ecuador y así aparecen en las tablas.

Las áreas de cinco grados están designadas por la latitud y longitud
su esquina sureste y han sido subdivididas en 25 áreas de un grado, que
tán enumeradas en serie desde la esquina sureste, como se ve en la
gura 1. El área 25-110 está dividida por la península de Baja California.
as porciones este y oeste de esta área de cinco grados están indicadas por
A" y "B", respectivamente, para los datos de los barcos rederos, ya que
tos pescan en ambas porciones. Tales designaciones no se usan para datos
los barcos de carnada, porque éstos normalmente no pescan mucho en
parte alta del Golfo de California.

standarización del esfuerzo de pesca

El éxito de la pesca para la obtención de atún aleta amarilla y barrite está relacionado con el tamaño de la embarcación. Shimada y Schaefer 1956) describen un método para ajustar el esfuerzo a una clase de tamaño stándar de barco que permita la comparación del éxito en la pesca efectuada por embarcaciones de las diversas categorías de tamaño que operan en do el Océano Pacífico Oriental Tropical. Ellos establecen seis clases de maño de barcos sobre la base de la capacidad para el transporte de escado, a saber: Clase 1, hasta 50 toneladas; Clase 2, de 51 a 100 toneadas; Clase 3, de 101 a 200 toneladas; Clase 4, de 201 a 300 toneladas; lase 5, de 301 a 400 toneladas; y Clase 6, de 401 toneladas y más. Las lases 4 y 3 se establecieron como estándar para los barcos de carnada y arcos rederos, respectivamente, y todo el esfuerzo de pesca se ajusta ntonces al equivalente de días de pesca empleados por estas clases de arcos. Los factores anuales de eficiencia correspondientes a los barcos de arnada y a los barcos rederos en los diez años, 1951-1960, están a punto e ser publicado por Broadhead (1962).

Para el propósito de este informe, los factores de eficiencia media btenidos del período de ocho años, 1951-1958, fueron usados en la estanarización del esfuerzo de pesca de la flota de los barcos de carnada urante los años 1951-1960. Los factores de eficiencia media correspondientes al período 1953-1958 fueron usados para los barcos rederos en el ismo período. Sin embargo, fué necesario un nuevo juego de valores edios para le estandarización de los datos de los barcos rederos, a partir e 1959, a causa del cambio precipitado en la composición y las característcas de la flota redera. Esto sucedió al operarse en masa la conversión de arcos de carnada en barcos rederos, asunto de que tratan Broadhead y Marshall (1961). Como los datos de los barcos rederos correspondientes al ño 1959 se prepararon en los comienzos de 1960, los factores de eficiencia alculados de los datos de 1959 fueron usados para ese año. Los valores romedio obtenidos de los datos de 1959 y 1960, se emplearon para estanarizar el esfuerzo de los barcos rederos en 1960. La siguiente tabla resenta los juegos de los factores de eficiencia empleados para estandariar el esfuerzo de pesca, correspondientes a los sistemas de captura, de onformidad con las clases de tamaño.

Tipo de barco y período	Clases de tamaño					
	1	2	3	4	5	6
Barcos de carnada 1951-1958	0.40	0.55	0.84	1.00	1.18	1.16
Barcos rederos 1953-1958	—	0.88	1.00	1.37	—	—
Barcos rederos 1959	0.60	0.82	1.00	1.30	1.20	—
Barcos rederos 1959-1960	0.66	0.73	1.00	1.35	1.27	1.01

Especies registradas

Las capturas registradas en los cuadernos de bitácora son tabuladas bajo cuatro categorías: atún aleta amarilla; barrilete; atún aleta amarilla y barrilete mezclados; y atún aleta amarrila o barrilete, no identificados separadamente. El computador fué instruido para prorratear los tonelajes en las dos últimas categorías, a la razón de los tonelajes identificados de atún aleta amarilla y barrilete registrados para cada área de un grado por trimestres del año. Alverson (1960) informa que las dos categorías de atún mezclado o no identificado juntas, contenían, en el período 1951-1958, un 9.7 por ciento del tonelaje registrado por los barcos de carnada y un 6.4 por ciento del tonelaje registrado por los barcos rederos.

Modificaciones en los datos

Algunas errores de perforación de menor importancia fueron encontrados en las tarjetas originales durante el manejo de los datos con el computador de la IBM 650. Estas tarjetas defectuosas, que fueron rechazadas por el computador, se estimó que contenían menos del uno por ciento de los datos, basados en las comparaciones entre los totales trimestrales y anuales de la captura y el esfuerzo compilados por la Comisión y el Buró. El uso de factores de eficiencia media, en vez de los valores anuales, para la estandarización del esfuerzo, también dió como resultado diferencias menores entre los datos presentados en este trabajo y los publicados por Alverson (1960). La comparación de las tabulaciones presentes hechas a máquina referentes a una serie de áreas con las de la Comisión ha indicado que las diferencias son insignificantes, cuando se usan datos para el examen de los cambios en la disponibilidad del atún por estratos de tiempo y de área.

RESULTADOS

Las Tablas 1 y 2 contienen el esfuerzo estandarizado y la correspondiente pesca por día estándar de actividad (SDF) registrados por los barcos de carnada y los barcos rederos para el atún aleta amarilla y barrilete, por área de cinco grados, por mes y por año, y para cada sistema de captura empleado. Como lo hizo notar Griffiths (1960), debe tenerse cuidado al tomar en cuenta los datos que están basados en menos de cinco días de actividad en la pesca, porque los esfuerzos pequeños a menudo generan medidas de la abundancia aparente del atún en las que no puede confiarse.

Para examinar las tendencias estacionales en la abundancia aparente, los datos de las áreas de cinco grados han sido consolidados en diez grandes divisiones geográficas de la pesquería, como puede verse en la Figura 2. Estas regiones corresponden muy de cerca a las usadas por la Comisión del Atún en sus estudios sobre la edad, el crecimiento, desove y la madurez sexual de las especies tropicales, pero no indican necesariamente los límites naturales de las poblaciones.

Las tendencias mensuales en la pesca por cada día estándar pueden apreciarse en las Figuras 3-12, en las que se han utilizado solamente los datos de los barcos de carnada. Los datos correspondientes al atún aleta amarilla se indican por las líneas ininterrumpidas, y las correspondientes al barrilete, por las líneas a guiones. El monto del esfuerzo de pesca usado para calcular la pesca por día estándar de actividad, se expresa con el número adyacente al punto que corresponde a cada mes; los meses en que no hubo esfuerzo se dejó en blanco. El tonelaje registrado en los cuadernos de bitácora, por especies, puede ser estimado al multiplicar el número de días de actividad en la pesca por la captura (en toneladas) por día estandarizado de actividad. El tonelaje registrado en los cuadernos de bitácora es menor que el total de la captura en esa área, porque unos pocos de los grandes barcos de carnada y rederos no llevan registros de bitácora y también diversas pequeñas embarcaciones que pescan los atunes tropicales no mantienen a bordo tales registros. Alverson (1960) anota que la cobertura de los cuadernos de bitácora varía desde el bajo porcentaje de 61.4 en 1951, cuando la Comisión comenzó su sistema de registro de cuadernos de bitácora, hasta la alta cifra del 82.1 por ciento en 1958; en 1959 y en 1960 se logró una covertura de un 75.6 y de un 80.8 por ciento, respectivamente. El promedio general correspondiente a un período de diez años fué de un 76.6 por ciento. El hecho de que los datos de los cuadernos de bitácora no sean obtenidos sobre el ciento por ciento de las pesca, no afecta significativamente la cifra que corresponde a la captura por día estándar de actividad, ya que el muestreo de los cuadernos de bitácora es suficientemente grande y comprende una buena estratificación en cuanto a tiempo y área.

El examen de las tablas y cartas demuestra que el éxito en la pesca de atún en cualquier área de cinco grados frecuentemente presenta una alta variación de un mes a otro dentro de un mismo año, así como entre años en el mismo mes. Estas variaciones son aún mayores en las áreas de un grado. Los factores que afectan o controlan la disponibilidad de los atunes tropicales son intensamente complejos. Por el momento no se intenta relacionar las variaciones en la tasa de la captura y en la captura global con las condiciones ambientales y biológicas. Sin embargo, estos datos básicos serán útiles a los científicos del Buró de las Pesquerías Comerciales, de la Comisión del Atún, y de la Institución Scripps de Oceanografía en los estudios de esta naturaleza que se encuentran al presente en camino.

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Phosphorus Content of Some Fishes and Shrimp in the Gulf of Mexico

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Abstract

The total phosphorus composition was determined for ten species of fish and one species of shrimp found in the coastal and bay waters of Galveston, Texas. The results of the analyses, which were based on the entire animal, were compared with the few similar analyses that have been made on other marine species. Shrimp contained about 1.46% P of dry weight (0.35% of wet weight). Fishes contained 2.43 to 3.81% P of dry weight (0.47 to 0.84% of wet weight). A brief discussion of the biogeochemical phosphorus cycle is included.

Phosphorus is one of the most measured ingredients of sea water. This element in its ionic form as phosphate is vital to the production of plant life, and most marine scientists, therefore, consider it significant as an indicator of productivity. Phosphorus also occurs in particulate and dissolved organic compounds and in organisms. The importance of this element in food has resulted in chemical investigation of marine products. W. O. Atwater (1892) determined the phosphorus composition of many food fish and invertebrates; later data were summarized by Vinogradov (1953). Most of the work was based on specific organs, tissues, or parts, rather than the whole animal. This paper presents the phosphorus content of various fishes and shrimp based on the entire animal. The specimens analyzed included inhabitants of the coastal and bay waters of Galveston, Texas, and an undetermined species of lantern fish (family Myctophidae) taken about 50 miles southwest of the Mississippi Delta.

These data will be useful in three ways: (1) deciding whether chemical composition varies between species, (2) determining the quantities of phosphorus in the biomass of higher organisms, and (3) determining the annual loss of phosphorus from the sea through the harvest of fishery products.

Chemical Analysis

The organic phosphorus in the dried or partially ashed (8 hr at 500–600°C) specimen was converted to inorganic forms by a sulfuric-nitric acid digestion. After digestion the residue was fumed down to about half its volume to reduce a by-product of the digestion reaction, nitrosyl sulfuric acid. This was necessary to prevent interference from the by-product in the subsequent phosphorus analysis. The sample was cooled and a portion of it diluted to the equivalent of about 10,000 ml per gram dried sample weight. Two sets of aliquot samples were prepared for analysis. One contained 1 ml of the diluted specimen mixture and the second, 3 ml. The samples of both sets were diluted to 25 ml with distilled water. The analytical method employed was that described by Robinson and

Thompson (1948). Control samples were prepared from KH_2PO_4 and also from a dried powdered fish mixture of known phosphorus composition. The purpose of the latter was to detect interference due to the nitrosyl sulfuric acid in the samples. Each specimen was analyzed four times. The precision of the average of the four analyses per specimen was estimated to be 0.1 mg P per gram sample weight (dry basis). The analyses are tabulated in Table 1.

TABLE 1

Phosphorus content of certain fishes and shrimp

Species	No. of specimens	Average weight		Per cent of phosphorus		
				Wet weight	Dry weight	
		Wet g	Dry g	Average	Average	Standard deviation
Lanternfish (Family Myctophidae)	34	1.2	0.26	0.82	3.11	0.37
Searobin *Prionotus tribulus*	12	7.2	1.89	0.84	3.20	0.71
Broad killifish *Cyprinodon variegatus*	24	1.1	.26	0.70	3.08	0.33
Spot *Leiostomus xanthurus*	14	35.6	7.94	0.51	2.29*	0.36
8-fingered threadfin *Polynemus octonemus*	22	4.2	0.78	0.55	3.00	0.70
Catfish *Galeichthys felis*	10	20.7	4.85	0.82	3.49	0.27
Ling *Phycis floridanus*	22	46.8	8.99	0.47	2.43	0.24
Anchovy *Anchoviella mitchilli*	19	.....	0.06	.....	2.91	0.24
Mullet *Mugil cephalus*	16	20.5	5.10	0.83	3.31	0.49
Mullet *Mugil cephalus*	15	.....	0.04	.....	2.53	0.25
Menhaden *Brevoortia patronus*	14	27.0	6.72	0.80	3.39	0.66
Menhaden *Brevoortia patronus*	19	0.7	0.13	0.76	3.81	0.54
Shrimp—Male *Penaeus setiferus*	7	22.7	5.41	0.36	1.49	0.09
Shrimp—Female *Penaeus setiferus*	17	23.7	5.64	0.34	1.41	0.27
Shrimp (sex unknown) *Penaeus setiferus*	25	.....	1.44	.....	1.47†	0.34

* Phosphorus analyses performed on "ashed" samples.
† Phosphorus analysis of 10 specimens was performed on "ashed" samples.

Discussion

We were not able to find any reference to phosphorus data, based on the entire animal, of the species we analyzed. However, analyses of entire organisms have been reported for other species. Sempolowsky (1889), cited in Atwater (1892), reported phosphorus contents of 0.53 and 0.78%, based on the entire fish, for the haddock (*Melanogrammus aeglefinus*) and the gray gurnet (*Trigla gurnardus*). Weigelt (1891), cited in Vinogradov (1953), reported 0.52–0.56% and 0.45–0.51% (whole weight basis), respectively, for the same species, 0.36% for the sea herring (*Clupea harengus*), 0.57–0.61% for the cod (*Gadus morrhua*), and 0.43% for the anglerfish (*Lophius piscatorius*). We

are aware of only one study of fresh-water fish in which the entire animal was analyzed for phosphorus. McCay *et al.* (1931) in nutritional studies of fresh-water trout (*Salvelinus fontinalis*) reported a range of 0.24–0.55% based on the entire fish.

Milone (1896), cited in Vinogradov (1953), reported a substantial decrease in phosphorus content with size for two species that he analyzed. The phosphorus content of Mediterranean species (*Smaris vulgaris*) was 0.53 and 0.89% (whole weight basis) for large and small specimens, respectively. Similarly, he reported values of 0.34 and 1.10% (whole weight basis) for the surmullet (*Mullis surmuletus*). Analysis of the menhaden (*Brevoortia patronus*) and shrimp (*Penaeus setiferus*) data (Table 1) shows no significant difference in the phosphorus content of large and small specimens. There appears to be a significant difference, however, in the phosphorus content of the two groups of mullet (*Mugil cephalus*).

The higher phosphorus content of fish as compared to shrimp was undoubtedly due to the high phosphate content of bone. The bones of many fish contain up to 65% mineral residue (Roche and Bullinger 1939), the $Ca_3(PO_4)_2$ content of which has been reported as high as 94% (Vinogradov 1953). Fish scales from some species also contain large amounts of phosphorus. Carnot (1893) was cited by Vinogradov (1953) as having reported values as high as 98.38% as $Ca_3(PO_4)_2$ for the mineral content of certain scales. The phosphorus content of the soft parts of fishes averaged about 0.3% on a whole weight basis (Vinogradov 1953), but variation among species is quite large. Krukenberg (1877) was cited by Vinogradov (1953) as having reported 0.032% for the dogfish (*Acanthias vulgaris*), and Javillier and Cremieu (1928) report 0.93% for the carp (*Cyprinus carpio*). This variation may reflect results based on individual specimens rather than on the mean of a number of fish (Vinogradov, 1953).

Shrimp show (Table 1) little difference in phosphorus content between sexes or size groups. The values shown (1.41–1.49%) are somewhat higher than that of Decapoda, in general, which range from 0.63–1.36% on a dry weight basis (Vinogradov, 1953). Again, we were unable to make a direct comparison with work on *Penaeus setiferus*. Weigelt (1891), cited in Vinogradov (1953), reported a value of 1.27% (dry weight basis) for *Crangus vulgarius*, and Delff (1912), also cited in Vinogradov (1953), reported 1.08% for the same species.

It is not the purpose of this paper to delve into the biogeochemical aspects of phosphorus, other than to mention that the phosphorus content of marine animals constitutes an important source for the return of this element to the land. Hutchinson (1952) stated that based on Clark's (1889) estimate, approximately 13.7 million tons of phosphorus are delivered to the oceans annually. The biogeochemical paths of return are considerably less than this (Hutchinson, 1952), and as a result, phosphorus at the surface of land masses may be decreasing. Hutchinson (1952) stated that the annual return of phosphorus to the land by fisheries of the world, based on an annual catch of 25–30 million tons, is about 60,000 tons. The estimate would assume an average phosphorus value of about 0.25% which is considerably less than the values shown in Table 1. We therefore believe his estimate to be conservative.

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THE CARLSBERG FOUNDATION'S
OCEANOGRAPHICAL EXPEDITION ROUND THE WORLD 1928—30
AND PREVIOUS "DANA"-EXPEDITIONS
UNDER THE LEADERSHIP OF THE LATE PROFESSOR JOHANNES SCHMIDT

DANA-REPORT No. 55.

IDENTIFICATION OF LARVAE OF FOUR SPECIES OF TUNA FROM THE INDO-PACIFIC REGION I.

BY

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WITH 5 FIGURES IN THE TEXT

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INTRODUCTION

There has been increasing interest concerning the early life history of the tunas in recent years throughout various parts of the world, particularly in those countries directly concerned with commercial exploitation of these fish. As a result a number of papers dealing with the identification of larvae and postlarvae of the tunas and closely related fishes have appeared in the literature. To date, identifications of at least six species [*Neothunnus macropterus* (Temminck and Schlegel), *Katsuwonus pelamis* (Linnaeus), *Euthynnus yaito* (Kishinouye), *E. lineatus* (Kishinouye), *E. alletteratus* (Rafinesque), and *Auxis thazard* (Lacépède)] have been published. The identification of *A. thazard* remains doubtful, since there is no way to separate the young of this species below 200 mm. fork length[1] from that of another species, *A. thynnoides* (Bleeker), belonging to this genus (Matsumoto, 1960).

In addition to these, Sella (1924) has described the early stages of *Orcynus thynnus* (Lütken) [= *Thunnus thynnus* (Linnaeus)] and *O. alalonga* (Risso) [= *T. alalunga* (Gmelin)] from specimens collected in plankton net hauls and at night-light stations, generally from the Strait of Messina. Sanzo (1932, 1933) also has described the earlier stages of *T. thynnus* and *O. germo* (Lütken) [= ? *T. alalunga* (Gmelin)] based on specimens that had hatched from eggs taken in plankton net hauls in the Strait of Messina, and which he kept alive up to 7 days after hatching. The identifications of these larvae are somewhat dubious, however, since the spawning seasons for both species, as well as for other species of tuna, are known to overlap with respect to time and duration, and although the plankton hauls were made during specific migratory runs through the Strait, there is no definite assurance that the eggs of one species were taken exclusive of the other.

In the Pacific, there has been no success until recently in identifying larvae of thunnids, except that of *N. macropterus* (Schaefer and Marr, 1948a; Wade, 1951; Mead, 1951; Matsumoto, 1958). The primary reason for this has been the failure to catch juveniles of various sizes, especially those immediately following the postlarval stages, and adequate numbers of larvae and postlarvae from varied localities.

The term "thunnid", as used hereafter, refers to tunas possessing a completely scaled body.

Recently I was able to identify tentatively four species of thunnids, *Parathunnus sibi* (Temminck and Schlegel), *Thunnus germo* (Lacépède), *T. orientalis* (Temminck and Schlegel), and *Kishinoella tonggol* (Bleeker) [= *N. rarus* (Kishinouye)], among the larval tunas collected by the "Dana" during the 1928–30 round-the-world oceanographical expedition. In order not to get involved with the taxonomic relationships of Atlantic and Indo-Pacific tunas, I decided to study the larvae from these two areas separately, concentrating initially on larval specimens taken in the East Indies and Formosan waters because of the availability of adequate published records of adult tunas taken in these and adjacent areas. Because of unexpected success in identification and the importance of these findings, I decided to publish the results immediately, so that other investigators could benefit from them. Consequently, this report is limited to species identifications and to a general description of each species. A subsequent report will include detailed descriptions of developmental changes for each of these species, as well as for other species not covered here or in my previous report (1959), and discussions of distribution and other aspects related to the larvae.

[1] Fork length is defined as the distance from tip of snout to tip of middle ray of caudal fin.

In order to avoid digressions concerning the nomenclature of the tunas found in different oceans and in different parts of the world, I have used the earliest accredited generic and specific names I could find for the Indo-Pacific tunas.

I wish to express my gratitude to the late Dr. Å. Vedel Tåning, who allowed me to examine the collection of scombrid larvae taken by the "Dana" and other Danish vessels, and his successor, Dr. E. Bertelsen, who permitted me to continue using this material. I wish to thank also Vernon E. Brock and John C. Marr, for their timely encouragement; Tamotsu Nakata, for the chart and illustrations; and staff members of the United States Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii, who carefully reviewed and criticized the manuscript.

METHOD

Except for artificial fertilization of ova and rearing of larvae of definitely known species in either shipboard or shore laboratories, a method that has proven extremely difficult and unsuccessful, the best method of studying species identification of larval tunas is to identify a series of juveniles and to trace their descriptions through smaller and smaller individuals, seeking and using larval characters as those of the adult gradually become less usable. This method has been used with some success in the past in identifying larvae of *K. pelamis*, *N. macropterus*, *E. alletteratus*, *E. lineatus*, *E. yaito*, and *Auxis* sp. (Ehrenbaum, 1924; Schaefer and Marr, 1948a, 1948b; Wade, 1951; Mead, 1951; Matsumoto, 1958, 1959). In the absence of known juveniles of various sizes, however, such a method cannot be used.

There is an alternative method that can be used in studying some of the presently unidentified species, and that is by comparing the species of adults taken by fishing gear and the "types" of larvae taken in plankton net hauls within the same area. Obviously, the occurrence of adult tuna in any area is not of itself a sufficient reason for assuming that spawning of that species takes place. The adult must be known either to spawn in an area (excellent evidence for this is the taking of fish whose gonads are in advanced stages of maturity or show signs of recent spawning), or be present in the area throughout the year or throughout the spawning months. Since juveniles of appropriate sizes were not available for any of the species, except *N. macropterus*, this method was used in identifying the thunnid larvae.

DESCRIPTION OF AREA AND OCCURRENCE OF ADULT TUNAS

Of the numerous "Dana" stations in the East Indies and Western Pacific at which plankton nets were used, larval thunnids were caught at only a few scattered stations which clustered about four general areas (fig. 1). Area I consists of the Celebes Sea, Sulu Sea, and the southern half of the South China Sea, where larval thunnids were taken in April and July; Area II is in the Indian Ocean immediately west of Sumatra, where larvae were taken during September and October; Area III consists of waters around Formosa and between Formosa and the Ryukyu Islands, where larvae were taken during May; and Area IV takes in waters near the northwestern coast of New Guinea, where larvae were taken in July.

Judging from Japanese longline fishing records (Nakamura, 1943; Nankai Regional Fisheries Research Laboratory, 1954, 1959), it may be assumed that *T. germo* is either extremely scarce or completely absent from Area I. *T. orientalis* also may be absent, since the fishery for the adults, according to Nakamura, begins in the northern part of the South China Sea and moves northeastward. Warfel (1950) also states that in the Philippine Islands this species is taken only off northern Luzon. The only species of thunnid, other than *N. macropterus*, which is recorded in Japanese longline reports from this area is *P. sibi*.

Regarding *P. sibi*, Yuen (1955) indicates that fish in near spawning condition have been taken in the western Pacific (Marshall and Caroline Islands) and the central Pacific from April through October. He gives the size of fish at the time of initial spawning as 14—20 kg., which is equivalent to 87—98 cm. total

Figure 1. Areas and positions where larval thunnids were captured by the "Dana" and the "Spencer F. Baird".

length[2]. Kikawa (1953) gives a similar range of 90—100 cm. for *P. mebachi* (= *P. sibi*) from the Marshall Islands. On the basis of these reports it can be assumed that the months of the year when plankton hauls were made by the "Dana" (April and July) in Area I coincided with the spawning season of the species. Furthermore, from length-frequency data of *P. sibi* taken in Philippine waters in March, May and November, 1954; March, 1957; and March, 1958 (Investigative Society of Tuna Fishery, 1954—1959)[3] it is known that about 95 per cent of the total catch consisted of fish capable of spawning, i.e., over 90 cm. total length. Consequently, although data from observation of gonads are lacking, the presence of adults throughout the known spawning months makes it highly probable that *P. sibi* spawns in this Area.

[2] Based on length-weight relation, log weight = −7.1167 + 2.9304 log fork length, calculated for *P. sibi* from Hawaiian waters by the Bureau of Commercial Fisheries Biological Laboratory, Honolulu.

[3] *Tuna Fishing*, Nos. 11, 13, 19, 45, 55.

A species which is not taken on longline, but which is known to occur in Area I is *K. tonggol* (northern bluefin). Although the geographical distribution of this species is quite extensive, as is shown by records from southern Japan (KISHINOUYE, 1923), throughout the Indo-Malayan region to southern Australia, westward to the Maldive Islands, and eastward to Papua and New Britain (SERVENTY, 1942), it is interesting to note that its occurrence is restricted to inshore waters. It is generally taken by surface trolling within the 100-fathom line (SERVENTY, 1956). SERVENTY (1942) reports that adults of this species weighing 11 to 42 lbs. are common in southern Australia and that (1956) fish with spent gonads have been caught during the summer and early fall (December to May) in the vicinity of New South Wales. Adults of this species are also present in southern Japan, where 13 lbs. is regarded as the average weight and 26 lbs. as the maximum (KISHINOUYE, 1923).

In the Philippine Islands, WARFEL (1950) reports a large specimen weighing 11.5 lbs., which, according to SERVENTY's data, must be considered an adult. He also reports that the average weight of this species taken there is less than 5 lbs. and that it is not abundant. On the basis of these various reports it appears as though *K. tonggol* generally spawns in the higher latitudes and does so only to a limited extent in equatorial waters. Moreover, because its distribution is restricted to inshore waters, it is very likely that larvae of this species would be absent from the offshore positions at which plankton net hauls were made by the "Dana" in Area I.

In Area II, adults of three species of thunnids taken on longline are recorded (NAKAMURA, YABUTA and MIMURA, 1955; NANKAI LABORATORY, 1954, 1959). They are *N. macropterus*, *P. sibi*, and *T. germo*. *N. macropterus* is not discussed here, except to mention that those taken on longline are predominantly large fish. Insofar as *P. sibi* is concerned, fish of spawning sizes (those larger than 90 cm.) comprised 96 percent of the total catch for August, September, and October 1954, September 1956, and August 1957 (INVESTIGATIVE SOCIETY OF TUNA FISHERY, 1954—59)[4], comparable in season with the months (September and October) when plankton hauls were made by the "Dana" and within the known spawning season of this species. Hence the probable spawning of *P. sibi* in this Area is clearly indicated.

Concerning the size at maturity and the spawning season of *T. germo*, UEYANAGI (1957) and OTSU and UCHIDA (1959) report that the size at maturity of females in the western and central Pacific is about 90 cm. While they do not define the extent of the spawning season, not having gonad samples for all months of the year, they present some evidence that this species is a summer spawner. OTSU and HANSEN (MS.), who examined gonad samples from the South Pacific, also present similar results. If *T. germo* in the Indian Ocean mature and spawn like those of the Pacific, it is highly probable that larvae of this species would be present in the plankton net hauls taken by the "Dana" in waters west of Sumatra, since September and October, the months when the plankton hauls were made, roughly represent the summer months at or near the Equator and adults are known to occur in Sumatran waters during these two months, as well as in other months of the year (INVESTIGATIVE SOCIETY OF TUNA FISHERY, 1954—59)[5].

K. tonggol is not listed among the species represented in the Japanese longline catches, but because of its wide distribution throughout the archipelago and of its occurrence as far west as the Maldive Islands in the Indian Ocean, the possible presence of this species in Sumatra cannot be overlooked. As explained in the discussion for Area I, however, it is not likely that this species would be present in the larval samples from Area II, since thunnid larvae other than those of *N. macropterus* were found only in hauls taken well beyond the 800-fathom line.

Another species, *T. maccoyii* (CASTELNAU) or southern bluefin, is found in waters adjacent to this Area, but it is known that the fishery for this species begins south of Java between 110° and 120°E. longitude in September and October, moves westward to about 100°E. longitude by February, and then moves back east of 110°E. longitude by March and April, after which the fish migrate south along the west coast of Australia (MIMURA, 1958). None are taken as far north as 5°S. latitude west of Sumatra until March, when only incidental catches are made. Since the thunnid larvae taken west of Sumatra were collected during the months of September and October, when adult *T. maccoyii* are generally caught to the east of 110°E. longitude and south of 8°S. latitude, it may be assumed that larvae of this species are not present in the "Dana" collection from this Area. Further-

[4] *Tuna Fishing*, Nos. 16—18, 39, 48.
[5] *Tuna Fishing*, Nos. 17 and 18.

more, there is little likelihood that eggs and larvae of this species drift northwestward along the coast of Sumatra, since the surface current in this region is to the southeast throughout most of the year (Nakamura, 1943).

In Area III, four species of thunnids, *N. macropterus*, *P. sibi*, *T. germo*, and *T. orientalis*, are generally present during April—June (Investigative Society of Tuna Fishery, 1954—59; Nankai Laboratory, 1954, 1959), comparable with the month (May) when thunnid larvae were taken by the "Dana" and with the spawning season of the first three species. *K. tonggol* is also known to occur here, and Nakamura (1943) reports that all of these species, except *T. orientalis*, which appears from April to June, are present in Formosan waters throughout the year. Insofar as *T. orientalis* is concerned, the size at maturity has not been determined. For *T. thynnus*, however, Frade (1937) reports a female 126 cm. in total length from Tunisian waters as having gonads containing predominantly ripe eggs, an indication of sexual maturity. Moreover, *T. thynnus* has been known to spawn in early summer, May -June, in the Atlantic and Mediterranean (Frade, 1937; Rivas, 1954). If *T. orientalis* is synonymous with *T. thynnus*, as many believe, then it should spawn in Formosan waters during the summer, since most of the fish caught there on longline during April—June are larger than 140 cm. (Investigative Society of Tuna Fishery, 1954—59)[6], well beyond the size of the mature female reported by Frade (1937).

Area IV is not included in the discussion because no longline catch record is available for the month of July from the vicinity where plankton net hauls were made. Thus, insofar as the occurrence of probable spawners, exclusive of *N. macropterus*, in these waters is concerned the following situation prevails:

Area	Probable spawners
I	*P. sibi*
II	*P. sibi; T. germo*
III	*P. sibi; T. germo; T. orientalis; K. tonggol*

IDENTIFICATION OF SPECIES

In the following sections larvae of *N. macropterus* are neither discussed nor described in detail because they have already been identified by a number of authors (Schaefer and Marr, 1948a; Wade, 1951; Mead, 1951; Matsumoto, 1958). In order to avoid any misunderstanding concerning the presence or absence of this species, because of its exclusion from the discussion, it is here emphasized that yellowfin larvae were found in large numbers throughout all of the Areas described above.

Matsumoto (1958, 1959) has shown that larval tunas can be diagnosed successfully by characteristic pigmentation in certain parts of the body. Preliminary examination of all probable thunnid larvae collected by the "Dana" from Indo-Pacific waters indicated that this method would be quite applicable to segregating the various forms represented in the catches. Detailed examinations, therefore, were made of the specimens, and the numbers and positions of chromatophores on the dorsal and ventral edges of the body, exclusive of the caudal fin, were noted as accurately as possible. They were symbolized as $\frac{0}{1'}$ $\frac{1}{2'}$ $\frac{2}{3}$, etc., the upper figure representing the number of chromatophores along the dorsal edge and the lower figure representing the number of chromatophores along the ventral edge. The number of different forms or "types" of larvae obtained in this way (28) far exceeded the number of species represented in the adult catches (4). Evidently there was considerable variation in the number of chromatophores on either the dorsal or ventral edge, and a grouping of the types was necessary. By using the dorsal chromatophores as the basis for this grouping, since they exhibited less variation than those located ventrally, the following six types were obtained: $\frac{0}{1-5'}$ $\frac{1}{1-7'}$ $\frac{2}{1-7'}$ $\frac{3}{1-5'}$ $\frac{4}{2-4'}$ $\frac{5}{2-3'}$

[6] *Tuna Fishing*, Nos. 1, 12, 13, 23, 24, 34, 35, 36.

Parathunnus sibi and *Thunnus germo*

In Area I, where only adults of *P. sibi* are known to occur in the vicinity where thunnid larvae were taken, all the larvae examined were of the type represented by $\frac{0}{1-5}$. In order to determine how this compared with samples taken from the same area in other years, I examined the larvae collected during 1947—49 by the "Spencer F. Baird"[7] of the U.S. Fish and Wildlife Service. Thunnids other than *N. macropterus* were found at 11 stations (fig. 1), but only one type of larva, similar to that collected by the "Dana", was found. In Area II, where adults of *P. sibi* and *T. germo* are known to occur, the larvae fell into two types, $\frac{0}{1-5}$ and $\frac{1}{1-7}$. Thus, type $\frac{0}{1-5}$, which was found in Areas I and II, was tentatively assigned to *P. sibi*, since adults of this species occur in both areas, and type $\frac{1}{1-7}$, which was found only in Area II, was tentatively designated as *T. germo*. As expected, larvae of both types were also found in Area III. Of the remaining four types, 261 out of 311 specimens examined were of type $\frac{2}{1-7}$, 41 were of type $\frac{3}{1-5}$, 5 were of type $\frac{4}{2-4}$, and 4 were of type $\frac{5}{2-3}$. The small numbers of the last two types seemed to indicate that they might be variations of the preceeding two types, which were taken as representing *T. orientalis* and *K. tonggol*. For the time being these were grouped together as bluefins, on the basis of two or more chromatophores on the dorsal edge of the body.

In order to verify these designations, the following hypothesis was set up: If the species designations are correct, then plankton samples from the central Pacific should contain larvae resembling those identified as *P. sibi* and *T. germo*, but not those of the bluefins, since one species of bluefin is absent from the area and the other is so rarely recorded that it could be regarded as being absent. Examination of thunnid larvae taken from the central Pacific from 1950 to 1958 by the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, in 11 cruises across the Equator between 180° and 130°W longitude showed the presence of only two types of larvae, which were similar to those designated as *P. sibi* and *T. germo*. No larva with two or more chromatophores on the dorsal edge of the body, as in the types designated as bluefins, was found. On this basis the species designations of *P. sibi* and *T. germo* ascribed to larvae from Areas I, II and III seem warranted. The result also confirms the tentative designation of the bluefins.

Thunnus orientalis and *Kishinoella tonggol*

The bluefins presented some difficulty, since larvae designated as such occurred only in one area. Consequently, species designations could not be made on the basis of areal comparison, as it was done with *P. sibi* and *T. germo*. It was necessary, therefore, to search for morphological characters showing species differences in the adults which would be usable also in separating the larvae. Tuna larvae do not possess completely developed morphological characters, except in the number of myomeres, until they are well over 10 to 12 mm. fork length; however, the initial stages of development of a few of these characters, such as the origins of the first and second dorsal fins, are quite noticeable on specimens as small as 6.0—6.5 mm. Consequently, the morphological character which seemed most promising in larval identification involved the dorsal fins and their relationship with the myomeres.

In many fishes, the number of spines and rays in the first and second dorsal fins, as well as the rays in the anal fin, can be used in species identification. The number of spines in the first dorsal fin, however, is usually expressed in figures representing either the total or most usual range of variations observed, so that even when a significant difference of one or two spines might exist between two species, the reported counts would not show this owing to overlapping of the ranges. In some species the range may represent actual variations, but in certain instances, such as that often encountered among the large tunas ,where there is a tendency for the last spine to become imbedded beneath the skin so that it is not noticed by the observer, the range could also represent variations that may only be apparent.

[7] Oceanographic research vessel of the U. S. Fish and Wildlife Service formerly used in the Philippine Fisheries Program.

An example of this may be seen in the spine counts of 214 *N. macropterus* from the central Pacific made by the staff of the Bureau of Commercial Fisheries Biological Laboratory, Honolulu. Of this number, 118 fish had 13 spines and 95 had 14 spines in the first dorsal fin. On the basis of this, one would consider 13—14 as the spine count for this species. If these fish are arranged by size groups, however, as is done below, it is clearly seen that the number of fish with 14 spines is greater than those with 13 spines in the two smaller size groups, but is much smaller in the two larger size groups. This is seen more conclusively in the results obtained from 43 juveniles, 10 -386 mm. fork length, and by counts obtained by Wade (1950) from 18

	Number of spines		
Size group (mm.)	12	13	14
400— 800.....	1	19	24
801—1200.....		11	27
1201—1600.....		50	32
Over 1601.....		38	12
Total...	1	118	95

juveniles 9.8—35 mm. fork length. In all of these juveniles there were 14 spines in the first dorsal fin, and in several instances specimens as small as 18 mm. were found with the last spine in a subcutaneous position. Therefore, although the spine count for adult *N. macropterus* may be given as 13—14 in many taxonomic reports, 14 must be considered the more accurate number for this species. This point is dealt with at length because part of the following discussion depends upon the number of spines in the first dorsal fin.

As for the bluefins, Rivas (1951) notes 14 or 15 as the number of spines in the first dorsal fin of *T. thynnus*. If *T. orientalis* is synonymous with *T. thynnus*, it should also have 14 or 15 spines. Kishinouye (1923) gives a range of 13—15 for *T. orientalis*, but the lower end of the range is suspect for the same reason cited above for *N. macropterus*. A count of 14—15 would be more likely for this species. This is attested to by the fact that Kishinouye illustrates a young *T. orientalis*, about 95 cm. in length, with 14 spines in the first dorsal fin. In contrast, the spine count for *K. tonggol* given by Serventy (1942, 1956) is quite consistent. He found 216 out of 237 fish (or 91.1 percent) with 13 spines in the first dorsal fin and only 9 fish with 14 spines. The validity of his count is enhanced by the fact that *K. tonggol* is a relatively small species, as tunas go, and therefore error in counting the last spine should be minimal. Kishinouye (1923) illustrates a specimen of *N. rarus* (= *K. tonggol*) with 13 spines in the first dorsal fin. Thus, for the purpose of separating *T. orientalis* and *K. tonggol*, the difference in number of first dorsal spines can be regarded as a reliable character.

Since the first dorsal fin is not completely developed on the larvae, however, the difference in the number of first dorsal spines noted in the adults of these species has to be interpreted through some other character closely related to it. The most obvious one is the position of the origin of the second dorsal fin, but before this character is used it is first necessary to establish the relationship between the last spine of the first dorsal fin and the origin of the second dorsal fin in terms of myomere number. Since neither juveniles nor adults of bluefin were available for examination, other species of tunas were examined, on the premise that if this relationship is consistent for other tunas, it should be consistent for the bluefins as well. The juveniles examined included 10 *K. pelamis*, 10 *N. macropterus*, 10 *E. yaito*, 5 *E. alletteratus*, and 5 *E. lineatus*, all of which possessed completely developed dorsal fins.

On all of the juveniles the last spine and corresponding pterygiophore of the first dorsal fin were on the myomere which was one greater than the total number of spines, and the first ray and corresponding pterygiophore, or the origin of the second dorsal fin, were located on the myomere following that which contained the pterygiophore of the last spine of the first dorsal fin. For example, in *K. pelamis*, a species having 16 spines in the first dorsal fin, the last spine and pterygiophore were located on the 17th myomere and the origin of the second dorsal fin was on the 18th myomere; in *N. macropterus*, a species having 14 spines in the first dorsal fin, the last spine and pterygiophore were located on the 15th myomere and the origin of the second dorsal

fin was on the 16th myomere. Consequently, the position of the origin of the second dorsal fin can be expressed as being on the myomere which is two greater than the number of spines in the first dorsal fin. Since this was true for all the species examined, it was assumed that it would be true also for the two species of bluefins. On this basis the origin of the second dorsal fin of *K. tonggol*, which predominantly has 13 spines in the first dorsal fin, and of *T. orientalis*, which has 14—15 spines, should be located on the 15th and 16th—17th myomeres, respectively.

In the larvae, neither the ray nor its corresponding pterygiophore, representing the origin of the second dorsal fin, develops until the growth of the larva is fairly well advanced. At a body length of about 6.0—6.5 mm., however, there begins along the base of the median membrane an accretion of tissue representing the incipient second dorsal fin. The anterior end of this accretion, which later becomes the origin of the fin, is clearly defined, so that specimens larger than 6.0—6.5 mm. can be separated by its position relative to myomere number, as discussed above.

In order to determine whether the bluefin larvae separated on this basis possessed significantly different pigment patterns, 50 *K. tonggol* and 22 *T. orientalis* were examined in detail. In all specimens of *K. tonggol* the initial or anteriormost chromatophore along the dorsal edge of the body was located anterior to the origin of the second dorsal fin, whereas on the 22 *T. orientalis*, the anteriormost chromatophore was located posterior to the origin of the second dorsal fin. On the basis of these observations regarding pigmentation, it was tentatively concluded that larvae having two or more chromatophores along the dorsal edge of the body, the anteriormost chromatophore being anterior to the origin of the second dorsal fin or the 15th myomere, are *K. tonggol*; and larvae having two or more chromatophores along the dorsal edge of the body, the anteriormost chromatophore being posterior to the origin of the second dorsal fin or the 16th—17th myomere, are *T. orientalis*. Larvae smaller than 6.0 mm. were thus identified by the location of the first chromatophore.

Of interest concerning the pigmentation along the dorsal edge of the body in both species is the occasional unusually large size of one chromatophore, which is found either at the base of the second dorsal fin or at one of the anterior dorsal finlets. This, however, is not true for all of the specimens examined, for in numerous instances all the chromatophores were of uniform size.

DISCUSSION

It might be well to point out that in the larvae it is often difficult to determine clearly the number of myomeres in the anterior and posterior extremities of the trunk. This problem was partially solved by examining juveniles cleared and stained in alizarin. The initial spine of the first dorsal fin of juveniles measuring 19 to 294 mm. fork length always occurred on the third myomere (this situation does not apply to adults, in which the initial spine is shifted posteriorly while the initial pterygiophore is elongated anteriorly into the second myomere), so that in instances where the anterior myomeres in the larvae were difficult to discern, the count was started at the third myomere or the origin of the first dorsal fin.

Regarding Sella's (1924) report, the description he gives of *A. bisus* (Bonaparte) [=*A. thazard* (Lacépède)] appears reliable, and my description of *Auxis* sp. (Matsumoto, 1958, 1959) generally agrees with his. Sella, however, fails to mention any pigment spot either at the symphysis of the pectoral girdle or at the anterior edge of the anal opening, which is of major importance in identifying this genus. It seems that Sanzo (1932) also failed to recognize this, for his figures 13 and 14 representing *T. thynnus*, plainly show a pigment spot anterior to the anal opening, indicative of the genus *Auxis*. It is very likely that eggs of this species were taken in the plankton hauls from which Sanzo obtained the eggs of *T. thynnus*, and that they were not distinguished.

Concerning *T. thynnus*, both Sanzo's description and figures 11 and 12 agree with the description given for this species by Sella in that generally two or more chromatophores are present along the dorsal edge of the body. In this respect, the description of *T. orientalis* presented herein also agrees with their descriptions.

As for the albacore, however, the description given by SANZO (1933) contradicts that given by SELLA (1924). Since both descriptions are rather sketchy, it is impossible to confirm either identification.

As a point of interest, SELLA (1924) refers to the pigmentation on the caudal fin in describing *O. alalonga* (= *T. alalunga* = *germo*?). He states that there are one to three chromatophores located dorsally or ventrally on the caudal fin. (This pigmentation is not to be confused with the chromatophores "along the dorsal edge of the body" mentioned previously). During the formation of the caudal fin, when the incipient urostyle is still in a horizontal position, this pigment is generally found near the tip of but ventral to the urostyle. After the urostyle has turned upward and the hypural fan is being formed, this pigment is generally found in the dorsal half of the posterior margin of the hypural fan (fig. 1—4). In the specimens I examined, during this and in my previous studies, usually one and often two or three chromatophores were found on the caudal fin in all species. Whenever there were two or three chromatophores, one of them was sometimes found dorsal to the incipient urostyle. In a check made on the larvae of *K. pelamis*, *N. macropterus*, and the four species tentatively identified herein, 14 out of 16 *K. pelamis*, 2 out of 6 *N. macropterus*, 31 out of 58 *P. sibi*, 26 out of 118 *T. germo*, 11 out of 60 *K. tonggol*, and 5 out of 18 *T. orientalis* were found to have this pigmentation. Because of such widespread occurrence in all of the species examined, and also because of variation in the number of spots, this pigmentation was not considered adequate for diagnostic purposes.

DESCRIPTIONS OF SPECIES

The descriptions presented here include those characters which I believe to be of importance for identifying the various species and some which are common to the thunnids, as represented in *N. macropterus*. Since only one illustration is presented for each species, it must be understood that all the variations noted on the larvae are not shown. These variations are, however, noted in the text. Furthermore, since the 6.0—7.0 mm. group represented the bulk of the catch, thus providing the best source of material for comparative purposes among all the species, all of the specimens illustrated are of this size.

Parathunnus sibi (TEMMINCK and SCHLEGEL)

This species (fig. 2) has several characters in common with *N. macropterus*. There are 40 myomeres in the trunk; the origin of the second dorsal fin is on the 16th myomere; there is no pigmentation over the forebrain, at the symphysis of the pectoral girdle, or along the dorsal margin of the trunk exclusive of the caudal fin. Pigmentation in the first dorsal fin appears quite early, after the development of the first 3 to 5 spines, and in instances where the first dorsal fin is well developed, with more than 7 or 8 spines, it is heavily pigmented.

Figure 2. *Parathunnus sibi*, 6.05 mm.

The only noticeable difference between it and *N. macropterus* is in the presence of pigmentation along the ventral edge of the trunk, which in *N. macropterus* is unpigmented. Although the figure shows two chromatophores, one on the 34th myomere, the other near the origin of the caudal fin on the 37th myomere, in other specimens the chromatophores may vary from one to eight and they may be located anywhere between the origins of the anal and caudal fins. Generally, however, the number of chromatophores is one to four. The only other tuna with similar pigmentation on the trunk is *K. pelamis*, but the number of myomeres, absence of pigmentation over the forebrain, and heavier pigmentation in the first dorsal fin distinguish *P. sibi* from this species.

Thunnus germo (Lacépède)

This species (fig. 3) is similar to *N. macropterus* and *P. sibi* in many ways. There are 40 myomeres in the trunk and the origin of the second dorsal fin is on the 16th myomere. There are no chromatophores over the forebrain in specimens less than about 9 mm. fork length, and none at the symphysis of the pectoral girdle. Pigmentation in the first dorsal fin appears early and is quite heavy when the fin is well developed. It differs

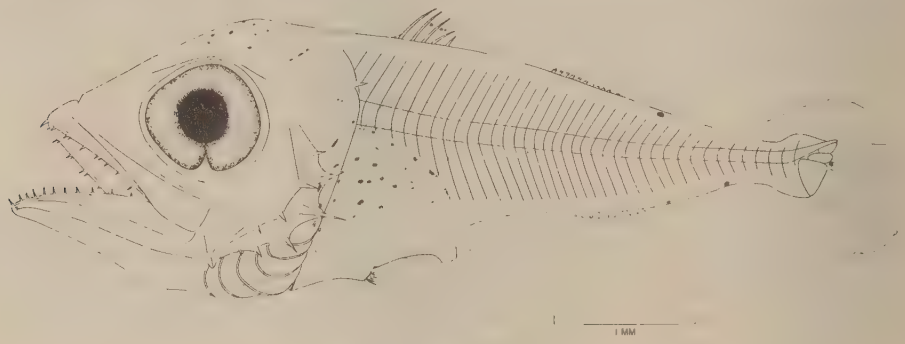

Figure 3. *Thunnus germo*, 6.47 mm.

from *N. macropterus* in having two chromathophores along the ventral edge of the body on the 28th and 33rd myomeres. As in *P. sibi*, the position and number of chromatophores on the ventral edge of the body vary considerably, there being generally one to five, and in rare instances up to seven.

The distinctive character which sets this species apart from *P. sibi* and *N. macropterus* is the single chromatophore on the dorsal edge of the trunk. On the figured specimen, it is located on the 27th myomere, at the base of about the third dorsal finlet. In other specimens, however, it may be found anywhere between the origins of the second dorsal and caudal fins.

Thunnus orientalis (Temminck and Schlegel)

This species (fig. 4) has 40 myomeres, and the origin of the second dorsal fin is on the 16th myomere. There are no chromatophores over the forebrain in specimens less than about 9 mm. fork length, and none at the symphysis of the pectoral girdle. Pigmentation in the first dorsal fin appears early and is quite heavy whenever the fin is well developed. In the specimen figured there are three chromatophores along the ventral edge of the body on the 27th, 30th, and 36th myomeres. As in *P. sibi* and *T. germo* the number and location of the ventral chromatophores vary among specimens. Generally there are one to six chromatophores situated between the origins of the anal and caudal fins. Unlike *N. macropterus* and *P. sibi*, this species generally has two or three chromatophores along the dorsal edge of the body between the origins of the second dorsal and caudal fins. In the figured specimen the two dorsal chromatophores are on the 28th and 31st myomeres.

Figure 4. *Thunnus orientalis*, 6.51 mm.

Kishinoella tonggol (Bleeker)

This species (fig. 5) also has 40 myomeres. The forebrain of specimens less than about 9 mm. fork length and the symphysis of the pectoral girdle are unpigmented. Pigmentation in the first dorsal fin appears early and is quite heavy when the fin is well developed. Although the figure shows two chromatophores along the ventral edge of the body on the 27th and 36th myomeres, in other specimens the number may vary from one to

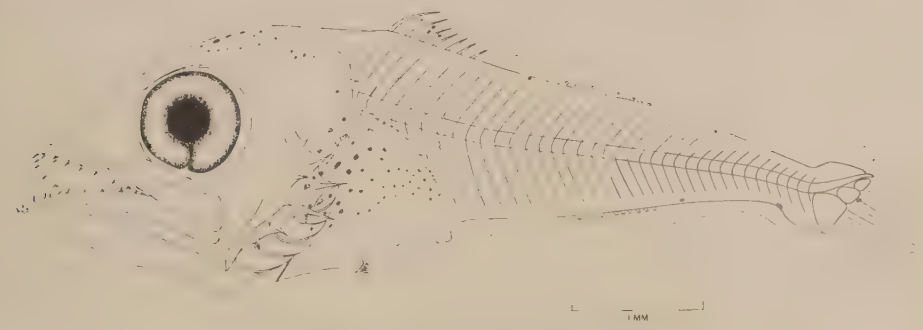

Figure 5. *Kishinoella tonggol*, 6.94 mm.

five and the position of each chromatophore may also vary as in the three species already discussed. There are two chromatophores along the dorsal edge of the body on the 13th and 28th myomeres in the figured specimen. The usual number of chromatophores in other specimens is two or three, but quite often there may be as many as five. In all specimens the initial chromatophore is found anterior to the origin of the second dorsal fin, along the base of the first dorsal fin, but the succeeding ones may be found anywhere between the origins of the second dorsal and caudal fins. This species differs from the three just described in having the origin of the second dorsal on the 15th myomere.

SUMMARY

Examination of larval thunnids collected from Indo-Pacific waters by the "Dana" during the 1928–30 round-the-world oceanographical expedition resulted in the tentative identification of larvae of four species of thunnids, *Parathunnus sibi* (Temminck and Schlegel), *Thunnus germo* (Lacépède), *T. orientalis* (Temminck and Schlegel) and *Kishinoella tonggol* (Bleeker), which have hitherto been unidentified. Inasmuch as another of the thunnids, *Neothunnus macropterus* (Temminck and Schlegel), has been identified and described by numerous authors, it was not included in this discussion. In order to avoid digressions concerning

the nomenclature of the tunas found in different parts of the world, the earliest generic and specific names given to tunas from this region were used.

Species identification was done by segregating the larvae from three localized areas into various "types" on the basis of number and position of chromatophores on the body, particularly the chromatophores along the dorsal edge of the trunk. The number of larval types in each area was then compared with the species composition of adult thunnids caught on longline fishing gear, including also a species (*K. tonggol*) which is known to be present in the areas, but which is not commonly taken on this gear.

All specimens examined had 40 myomeres and had little or no pigmentation over the forebrain. Larvae with no pigmentation along the dorsal edge of the trunk, exclusive of the caudal fin, but with one to five chromatophores along its ventral margin were designated as *P. sibi*. Larvae similar to *P. sibi* but having one chromatophore along the dorsal margin of the trunk, at the base of either the second dorsal fin or one of the dorsal finlets, were diagnosed at *T. germo*. Larvae similar to *P. sibi* but having two or three chromatophores along the dorsal edge of the body, the initial chromatophore being at the base of either the second dorsal fin or one of the dorsal finlets, were identified as *T. orientalis*. On all these three species, the origin of the second dorsal fin was located on the 16th myomere. Larvae similar to *T. orientalis* but having the initial dorsal chromatophore anterior to the 15th myomere or the origin of the second dorsal fin were designated *K. tonggol*.

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19. FISHERIES

Dr. J. L. McHugh

Bureau of Commercial Fisheries
Washington, D. C.

Fishing is one of the most primitive activities of modern man. Since fishing first began many thousands of years ago, there has been no substantial change in gear or methods. Today we still fish with essentially the same devices that our early ancestors used, the trap, the net, or the hook. Over the years, we have added various modifications, it is true, but these have merely served to increase the efficiency of catching with the same old gears. The major improvements have been power to allow boats to move more quickly and range more widely, power to reduce the labor and increase the speed of hauling nets or lines, and new materials to prolong the life and increase the catching power of nets. The only radical change has been the use of electricity for guiding fish, but even this has not developed into an entirely new method, for it is used in conjunction with net fishing.

The ACT OF FISHING has two distinct phases. First, it is necessary to locate the fish in sufficient quantity; second, to catch them and bring them aboard. Both operations depend on a knowledge of the habits of fish. Fixed gears rely on prior knowledge of migration paths, vertical distribution, or reactions to barriers. Moving nets rely on visual clues, like jumpers, "finners," bird concentrations, or the tell-tale color of a school of fish near the surface as seen from the crow's nest, but prior knowledge and experience play an important part, too. Hook and line fishing depends on the feeding habits of fish, and requires a knowledge of their feeding habits, vertical distribution, and movements. Various types of attractants, such as lights or disturbances of various kinds, may be used in conjunction with conventional types of gear. These depend on a knowledge of reactions to different kinds of stimuli. An interesting method, once used to locate schools of herring for seiners, employed a length of piano wire with a weight at the end, suspended over a man's finger at the bow of a slowly-moving boat. By feeling the vibrations caused by contact of herring with the wire, an experienced man could judge not only the size of the school, but its depth and direction of movement as well.

The ART OF FISH LOCATION has benefited more from modern technology than has the art of catching. Various types of sonic equipment have been used with some success for the past 20 years or more. Even the standard fathometer is useful for this purpose. With the most modern equipment, it is possible to determine the depth and numbers of fish, not only immediately beneath the vessel, but at distances of a mile or more. With experience, it is also possible to recognize the kinds of fish on the record. But much more needs to be done before the art of fish location can become a science. Perhaps waves other than sound waves will prove useful, and these should be investigated. It is interesting also that many fishes and other marine animals produce distinctive sounds. No one has yet put this knowledge to use in fishing.

The ART OF CATCHING FISH, as I have already mentioned, is one of the most primitive activities of man. This situation did not arise entirely by chance, for increased efficiency without regulation places an extra drain on the resource. Many laws limit the efficiency of fishing operations in the name of conservation. This often has been carried to ridiculous extremes, such as, forbidding the use of power in fishing boats. Science can help the fishing industry in two ways: by determining the maximum sustainable yield for each fishery resource, and by reducing the cost of catching fish to a minimum. But the tradition of conservation by inefficiency is so strong that it is difficult to put scientific management measures into effect even when our scientific knowledge justifies them.

Some of the most serious problems of our United States fishing fleet today are economic in origin. As the world's population grows, and the fleets of the major fishing nations range the world's oceans in search of protein food, it will be disastrous to the American fishing industry to operate under inefficient conditions. Indeed, because our living standards and our wages are higher than those of any other nation, our fishermen need to be more efficient in order to compete successfully. This will require the fullest use of instrumentation, both for locating and for catching fish.

Two recent developments show promise as radical new methods of fish catching. One is the air-bubble curtain developed by our New England scientists. The other is electrical fishing. It is known that when fish come within the influence of an electrical field, they orient themselves with respect to the gradient in potential and swim toward the positive pole. The dissolved salts in sea water create problems, and a purely electrical method of fishing has not yet been developed, but electricity is used in the menhaden catching operation, once the fish have been surrounded by the seine. The anode is placed on the end of the hose used for pumping the fish aboard, and the cathode is laid in the bottom of the net. This brings the fish to the hose, relieves the strain on the net, and speeds up the process. Electricity also is used successfully in fresh water for a variety of scientific purposes, such as sampling the fish life of a stream, killing predators like the sea lamprey, or guiding salmon past turbines in dams. Electricity, therefore, offers possibilities for locating, for guiding, and for catching fish. If the two operations could be combined, an important step would be achieved in reducing the cost of fishing. One way to do this might be to design an underwater trawler, a submarine-like vessel, with open mouth, which would attract fish to itself with electricity, then gulp them in. Such a vessel might even process the fish aboard, bringing a finished product back to shore.

The needs for instrumentation in FISHERY SCIENCE are many and time will not allow a complete account. (A special list is included in appendix H.) Better methods to measure abundance in the natural environment would be invaluable, for such information is now obtained quite indirectly by sampling, from tag returns, or from catch statistics. Particularly useful would be practical ways of estimating abundance of young, as a guide for planning future fishing operations, for fluctuations in abundance are sources of difficulty to the fishing industry. They usually are not anticipated, and thus, they add to the cost of fishing.

When migration pathways are restricted, direct counting may be possible. In narrow, clear streams, for example, migrating salmon can be counted by eye, but in broad or muddy streams this is difficult or impossible. Electronic counters have proven successful in restricted channels; but in broader streams, much of the width must be blocked in order to lead the fish to the counter. Barriers interfere with movements of fish in various ways, and may cause serious delays in reaching spawning grounds, to

the detriment of reproduction. What is needed is a successful method of scanning the water without using extensive underwater structures.

Our scientists have solved the physical problem of passing adult salmon upriver and young salmon down over low dams, and we think high dams can be conquered in a reasonable length of time. A difficult problem that still has to be solved, however, is to find a sure method to attract adult salmon to the entrance of a fishway. There also remains the problem of guiding fish without undue delay through the unfamiliar environment of the reservoir at a reasonable cost. One method might be to create a turbulent path from end to end, or in some other way to simulate the river that they seek. Some success has been achieved with electrical guiding, but more needs to be done, and other methods perhaps should be tried.

Another important series of problems exists in PLANKTON RESEARCH. These microscopic plants and animals are the basis of all organic production in the sea. Many fishes spend a part of their lives in this drifting world as eggs and tiny larvae. Plankton is also important food for many fishes. In collecting plankton for study and for estimation of abundance, fine-meshed nets usually are employed, but this is a cumbersome and awkward method. Many plankton organisms are so tiny that they can escape through finest mesh; others are sufficiently active so that they can escape the net mouth. Thus, nets of any kind give a biased sample at best. Something close to a complete sample can be obtained by bringing aboard a quantity of water by pump, or in a container, and separating the living organisms from the water by centrifuge. But plankton is relatively sparse, and large amounts of water must be handled to obtain a sufficient sample.

Although plankton samples taken with nets are biased, they still give useful information. One of the most successful ways of studying the distribution of plankton over large areas of ocean has been with the Hardy Continuous Plankton Recorder, which preserves a sample on a moving belt of fine-meshed silk. Later examination of this strip under a microscope permits reconstruction of the numbers and kinds of organisms along the path of the ship. This method is successful only in waters where plankton is relatively abundant, for the amount of water strained per unit area of sea surface is small. Moreover, the net fishes at only one level, and we know that the vertical distribution of plankton varies in time

and space. Some automatic method of fishing a sinuous path in a vertical plane, on the order of 300 feet from the ocean surface to the deepest part of the trajectory, is needed. More thought needs to be given also to methods of recording temperature, depth, and amounts of water strained by plankton samplers.

Solution of some of these problems of scientific plankton study may have commercial applications, too. Plankton is much more abundant in total mass of protein than the larger marine organisms. Hence, some people have suggested that plankton is the most effective source of food from the sea. The slow rate of harvesting by conventional methods, caused by the need to handle large quantities of water, has prevented development of a practical method. If this instrumentation problem can be solved, fish factories may become a thing of the past.

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LIVING MARINE RESOURCES

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Introduction

I am pleased to see that the final paper in this symposium deals with people. Too often it is forgotten that people, too, are a natural resource. Even more significant to the marine scientist, however, is the fact that our interest in natural resources, and our support of research on them, exist because these resources are useful in some way to people. This utility may be aesthetic, or it may be practical in the sense that someone may make a profit from it. Whatever the reasons, people and natural resources are inextricably entangled one with the other. We cannot study the resources intelligently without considering their utilization by people, nor can we do so without considering the effects of people upon the resource.

People, with their different social and educational backgrounds, their varying points of view, and their diverse economic and aesthetic interests, generate controversy. This is an essential part of our democratic way of life. At least four groups, each with unique backgrounds and interests, are involved in the controversies that concern Virginia's living marine resources. Commercial fishermen depend on these resources for most, if not all, of their livelihood. A growing body of saltwater sport fishermen gain healthful recreation from their hobby. The State Legislature makes the laws on which conservation of these resources is based, and tries to view fishery problems broadly in relation to other important uses of Chesapeake Bay and its estuaries. Public administrators, including scientists of the State and Federal Governments, have a duty to interpret and enforce the laws, make continuing surveys of the condition of the fishery resources, and develop a body of scientific knowledge from which wiser laws and more intelligent management can be based.

It is sometimes surprising, in view of the widespread disagreement on causes and cures of fishery problems of this region, that the basic truth is not more clearly recognized. It takes little effort to recognize that disagreement must signify inadequate knowledge. If we had the facts, and their meanings were analyzed clearly and properly disseminated, general agreement on the fundamental principles of conservation would follow. As it is, the need for greater understanding has been recognized and is growing, as demonstrated by the growing support of scientific research in both States that border the Chesapeake. But there is strong disagreement in segments of all interested groups as to the values and pertinence

of scientific findings to date. Indeed, it must be admitted that the scientists, themselves, have not always agreed on interpretation of their own data. When the facts are incomplete, there is always room for honest disagreement. The public should not be disillusioned when scientists fail to agree, nor should scientists become too discouraged when non-scientists disagree with them. Instead, all should rise to the challenge and plan for a gradual convergence of understanding.

Some of my academic colleagues tend to look down upon those of us who study fishery resources. They view our inevitable association with commercial fishery interests, sport fishermen, and lawmakers as a form of scientific prostitution. On occasion, they have been known to refer to us somewhat contemptuously as "politicians." I would suggest that those few who have adopted this attitude have failed to look deeply enough into our particular mission as marine scientists. People are an integral part of the environment we are studying.

I prefer to consider that the science of the living resource of the sea is the very broadest kind of ecology. As such, it includes the meteorological sciences, the physics and chemistry of the waters, the biology of the animals and plants of the sea, and of some freshwater, terrestrial, and aerial organisms as well. It extends to the geology of ocean shores and bottom, the engineering aspects of instrument design and function, the design of ships for scientific research and fishing, and the development of new and more efficient types of fishing gear. Finally, it concerns the interactions of all these forces one with the other, to produce the dynamic entity that we call the oceans.

It is important also to recognize the roles that man plays in the ecology of the sea. It is recognized widely that he influences the abundance of marine animals directly, by fishing, by killing organisms he regards as pests, or by protecting those he considers desirable. It is recognized also that he influences abundance indirectly, by polluting the waters, building bridges, dams, breakwaters, and other permanent structures, or filling marshland, dredging channels, and otherwise changing the biota and the topography. It is much less widely recognized that he exerts more subtle influences upon the economy of the sea by his peculiar ways of doing things or his peculiar habits of thinking. Thus, economics and social-political forces are important elements in fishery ecology, and these subjects deserve far greater attention than they now receive. I would say that the effects of man's activities are more often misinterpreted than judged correctly. When they are invoked for purposes of "conservation," as when fishery laws are formulated and enacted, more often than not the effects are quite different from what was intended. In the United States particularly, where fishery laws and enforcement are the prerogative of the individual States, some ridiculously provincial ideas and traditions hold

sway. In many States the fishery laws contribute to the sad economic state of the fisheries by making it impossible to harvest these resources economically. Thus, the study of mutual relationships among marine organisms and between them and their environment must extend beyond the boundaries of the ocean to include all the interrelationships with men. This is ecology in its very broadest sense, the only sense that will lead to full understanding of fishery dynamics.

Basic and Applied Research

In view of the title of this Symposium, some remarks about the definitions of basic and applied research are appropriate. Previous speakers have pointed out that these two kinds of research are difficult to separate, and that such separation is not necessarily important. I agree with this view. Nevertheless, these terms are in wide use today, and it might be well to consider how the two categories might be applied to the living resources of the sea. Several dichotomies might be selected, each of which would be unsatisfactory to some. One such division might be that applied research is research on individual species of particular interest more or less to the exclusion of their competitors, predators, or their environment in general. This classification would characterize basic research as the broad study of the species in relation to its environment. Many times in the past, government appropriations for fishery research have been restricted by law to the narrow concept represented by the first of these two definitions, and our knowledge has suffered thereby. It might be considered that these two concepts represent natural stages in the evolution of the science of fishery research. Fortunately, we now are moving rapidly toward the "sophisticated" view represented by the ecological approach. I prefer, however, to consider that all significant research is prompted by man's desire to know more about the world around him, and that any division of such research into basic or applied categories is quite artificial.

Virginia's Marine Resources

Let us look at a few important marine fishery resources of Chesapeake Bay, examine their history, their present condition, and their future prospects. I have chosen three, which I think are particularly appropriate for my purpose, one a mollusk, one a crustacean, and one a fish. These three account for about 75 percent of the total value of Chesapeake commercial fishery landings, and they are representative of the diversity in kinds of animals and types of life history that characterize the marine resources of this region. In selecting these examples I have omitted the growing salt-water sport fisheries of the region, which take large number of food fishes of a variety of species, some also of commercial importance. I have done this not because the sport fisheries are unimportant, for they provide recrea-

tion for a great many people, and constitute a major commercial enterprise as well. But time will not allow adequate treatment of all fishery resources, and the sport fisheries alone could easily occupy the entire period allotted to me.

The Oyster Resource

The oyster, of course, is the principal fishery product of Chesapeake Bay. The annual harvest is worth more than the total harvest of all other fishery resources combined. Except for a brief period after spawning, when the young are free-swimming, oysters are unable to move from the place where they first attached themselves to the bottom. For this and other reasons they are readily cultivated, and their numbers are controllable by man.

The naturally-producing oyster grounds in Chesapeake Bay are for the most part in waters of intermediate salinity. This is because oysters are able to tolerate fresher waters than their principal enemies and diseases, and because they are better protected from the effects of storms. Oysters however, cannot tolerate fresh water for any great length of ime. Thus, in Virginia the natural grounds are principally fairly well up the estuaries, but in Maryland, they are nearer the mouths of the estuaries or in the Bay, itself.

Seventy years ago oysters dominated Chesapeake Bay fishery landings. About 22 million bushels were produced in 1890. At today's prices these would bring to oystermen more than $77,000,000 for their catch. But landings in both States have declined rather steadily since the end of the 19th century, and in 1961 the total harvest was less than 6 million bushels, worth about $19,000,000.

The belief is quite generally held that the naturally-producing oyster grounds belong to the citizens of the States. Thus, Maryland and Virginia both have set these grounds aside as public grounds, and have enacted laws that regulate the taking of oysters. Both States also devote considerable effort to rehabilitation activities, planting shell back on the grounds to serve as clutch for the new crop. In other respects, however, the two States differ sharply in their oystering policies. Virginians believe that the oyster industry thrives best under a system of farming, and the State has a liberal policy of leasing barren bottom in the estuaries and in the Bay. Oyster planters improve this bottom, when necessary, by planting shell or otherwise preparing it for seeding. The State permits tongers to take young oysters from certain public grounds for planting on these otherwise barren grounds. Planters lease these grounds, at a nominal fee, from the State.

In Maryland, on the other hand, public policy generally has been opposed

o private planting. Proponents of private enterprise have prevailed at imes, and a small acreage of bottom is under lease, but this is quite mall in relation to the extensive area designated as public ground. The State spends rather large sums annually to plant shell on the public grounds, and also transplants oysters from one area to another.

How effective are these policies? More than 85 percent of Maryland's production is a wild crop, harvested from public grounds. Three-quarters of Virginia's production, on the other hand, is grown on private bottom. Virginians point with pride to the success of their more liberal policies, which have maintained fairly steady annual harvests for the past 40 years. Marylanders believe that their accelerated program of public management will halt the decline and will, in the long run, demonstrate its superiority over private enterprise. The facts seem to favor Virginia's view over Maryand's but it cannot be denied that that production has fallen substantially in both States. Obviously, something is wrong. Moreover, although State policies diverge sharply, opinion is by no means unanimous within and between factions. These battles are a conglomeration of lack of knowledge, prejudice, conflicting interests, and inefficient harvesting and management practices. It is only necessary to consider the Potomac River, where an estimated 42 square miles of oyster dredging grounds in the 1890's were reduced to about 11 square miles by 1942, or the Rappahannock and other estuaries in Virginia, where many formerly productive natural grounds now are barren, to realize that the fishery was removing more from these bottoms each year than nature was able to replace. Within the confines of your own city lies the body of water known as Lynnhaven Inlet, once known widely as a source of prime quality oysters. These famous Lynnhaven oysters came from naturally-producing grounds long since denuded, and this historic name now is but a memory to oyster lovers.

The Blue Crab Resource

The blue crab fishery has generated just about as much controversy in the Chesapeake Bay States as the oyster fishery, although the basic problems and the facts are not at all similar. In contrast to oysters, which are essentially sedentary animals, blue crabs perform extensive annual migrations, although it is believed that these migrations do not extend to any great degree beyond Chesapeake Bay. In late summer and fall, having been fertilized already, adult female crabs begin to migrate down the estuaries and down the Bay toward the deeper, saltier waters in Virginia near the Bay entrance. Here they spend the winter, more or less dormant, carrying the mass of developing eggs, or "sponge," attached to rudimentary legs beneath the abdomen. The young hatch the following spring and summer, and spend several weeks as feebly-swimming, drifting larvae, more or less at the mercy of tides and currents. Because the deeper, saltier

water moves slowly up-Bay and up the estuaries, the young crabs begin their first winter of life farther up the Bay and estuaries, and they resume this migration in spring as the water warms. By mid- and late summer, at an age of one year to a year and a half, they become adults, spawn, and the fertilized females begin their return migration. It is believed that few, if any, survive beyond three years.

The fishery uses a variety of gears and operates throughout the year in one area or another. The catch and the abundance of crabs fluctuates widely, but there has been no solid evidence that the yield is declining, despite the gloomy views that have been expressed from time to time. Nevertheless, the wide fluctuations create serious economic problems in the industry, and opinion is not unanimous as to the cause. A divergence of opinion exists similar to that surrounding oyster problems, and there are strong agreements and disagreements within and between States.

One rather common prejudice is a belief that it is harmful to catch crabs bearing eggs. Both States have enacted laws to prohibit capture of "sponge" crabs, and Virginia maintains a large sanctuary in the lower part of the Bay where pregnant females congregate in winter. In general, however, Virginia's crab laws are more liberal than Maryland's and Virginia has fewer gear restrictions and closed seasons. For these reasons, Marylanders are prone to blame the Virginia fishery when crabs are in short supply. But the scientific evidence leaves little doubt that environmental effects upon the success of blue crab spawning are more powerful than the fishery in determining abundance and future catches.

The Menhaden Resource

In terms of weight landed, menhaden support the largest fishery in Chesapeake Bay. Spawning takes place in late fall in the ocean, but the young soon enter the Bay and penetrate the estuaries into waters of low salinity. Here they spend the winter. In spring they begin to grow rapidly, moving slowly down the estuaries and the Bay. By fall, at one year of age, they are 5 to 6 inches long, and migrate to the ocean to winter farther south. Each year thereafter they make a northward migration in spring and summer and return to southern waters for the winter. In each successive year of life this migration extends farther north.

Menhaden are filter feeders, straining microscopic plankton from the water through their finely-spaced gill rakers. They occur in great abundance in Chesapeake Bay in summer, and they harvest great quantities of plankton. One of the airplane pilots whose job it is to spot menhaden schools for the seine boats once told me that often the murky waters of the Bay are miraculously clear immediately behind a menhaden school. This led me to wonder what the total plankton consumption of these abun-

dant fish might be. In the absence of better knowledge I had to make some assumptions. These were that a single menhaden strains a column of water one inch in diameter at a rate of one knot, and that the population of menhaden present in Chesapeake Bay is double the annual catch. These may be conservative assumptions, as I assumed, or they may be quite unrealistic, as the surprising result suggests. On this basis I came to the conclusion that the summer population of menhaden in the Bay could filter all the water in the Virginia portion of Chesapeake Bay and its tidal estuaries twice in 24 hours!

Ecological Implications

Menhaden also serve as food for the larger carnivorous fishes in the Bay. We know that striped bass and bluefish eat large numbers of menhaden at certain times. This has caused some people to think that menhaden purse-seining is harmful in two ways —— it competes with food and sport fishes for food, and it catches these desirable species along with the menhaden. These are two principal reasons why Maryland does not permit menhaden purse-seining.

These interrelationships are interesting and important, and we know far too little about them. Opinions play a large part in framing fishery laws, and this is a good example of the effect of foggy thinking upon fishery resources. Menhaden fishing is denounced vigorously at times because it is believed to affect the abundance of food fishes. But no one ever has suggested that menhaden should be eliminated because they eat large quantities of plankton. Yet blue crabs and oysters spend part of their early life as plankton organisms, where they are vulnerable to just such predation. Menhaden usually are most abundant in the Bay at exactly the times and places occupied by the newly-hatched blue crab larvae. It is possible that this could be a most important factor in determining blue crab abundance. Investigation of this interrelationship would be an exciting piece of basic research, which would tax the imagination of the most competent scientists. The problem has many ramifications, including the need to understand distribution in time and space, food habits, and the relation of these animals and their associates to their physical and chemical environment. I am sure that these relationships would turn out to be most complex, and that a simple inverse correlation between abundance of menhaden and blue crabs would not be found. Menhaden are typically unpredictable in their movements. Their food requirements, as calculated above, if this example is at all realistic, suggest why this is so. If they did not move about continuously and over a wide area, they might very well deplete their food supply.

Man-made Environmental Changes

As our population grows, and our industrial development becomes more complex, the characteristics of our marine environment are certain to change in many ways. Domestic and industrial wastes introduce a variety of new substances into the waters, some toxic, some oxygen-consuming, some perhaps beneficial. These substances begin to change as soon as they are introduced —— some are oxidized, some broken down by bacteria into simpler substances. But they also exert their own influences upon the marine environment, and cause changes in numbers and relative abundance of the different kinds of animals and plants. The gross changes, which sometimes cause spectacular mortalities, are easy to see and understand. But there are other, more subtle changes that we still know little about. For example, what effects do such wastes have upon the spawning of oysters, development and setting of their larvae, and their feeding, growth, and other metabolic activities at all stages of development? Experience in the western end of Lake Erie, a more or less self-contained body of water partly separated from the rest of the Lake by a chain of islands illustrates what can occur. Growing domestic and industrial pollution from the heavily industrialized area to the north, pouring into the Lake from the Detroit River, has caused spectacular changes. Water temperatures have risen appreciably, the dissolved oxygen content has dropped, and the animal population has changed in response. Insect larvae, such as those of mayflies, formerly abundant on the bottom, now have virtually disappeared. In their place have come great increases in numbers of pollution-loving forms, such as worms. It will be a long time before such dramatic changes take place in Chesapeake Bay, but some of our waters near sources of pollution are in as bad or worse condition already. But it is the smaller changes that occur in response to incipient pollution that are most difficult to detect and understand.

Costs of Research

Research in the marine environment is costly, and the costs have not been easy to justify. On what basis should we decide what amounts are justifiable as an investment in research on living marine resources? This problem is constantly before the research director of your State Marine Laboratory as he plans his requests for funds to present to the State legislature. The problem is constantly before appropriations committees and the executive heads of government as they try to fit increasing budget requests from a variety of worthy government agencies into a fixed estimate of revenues. Total requests are always larger than estimated revenues, and cuts necessarily must be made. If it is decided that research on the marine resources should be increased, the increase must be at the expense of some other agencies. It would be extremely useful to the

idget planner if he had an objective estimate of the amount he could asonably expect to receive.

One such estimate might be based on the value of the resource. The nnual value of Virginia's commercial fish catch, as paid to fishermen at ie point of landing, is about $20,000,000. If 5 percent is a reasonable roportion of the value of the catch to be invested in research, then the nnual budget should be about $1,000,000. If the research budget should e determined on the basis of retail value, then this figure should be about 2,500,000. To this might be added an amount based on an estimate of ie value of the saltwater sportfishery. No one yet has developed a tisfactory method of comparing the value of a commercial and a sport shery.

Other considerations must enter into such estimates if they are to be alistic. If it is decided that a certain percentage of the value of the source can be used to set the level of the research budget, should the costs management of the fishery and enforcement of laws be charged against is fund? Should the value of the fishery be based on present landings, should potential landings of latent resources be included? If certain pecies have been overfished, and present landings are well below the maxium sustainable yeild of the resource under scientific management, should e budget be based on the present or the potential yield? Should the timate of optimum research budget take into account the amounts being pent by Federal or other laboratories on the resources in question? These e but a few of the questions that need to be answered if budget levels e to be estimated and justified on such grounds.

Another method of estimating budgetary levels might be based on the gument that for each research objective there is a certain budgetary reshhold, below which there is little likelihood that the objective could e achieved. If this threshhold could be determined, then the annual idget might be decided in terms of the need for information. The time quired to reach the objective would be related inversely to the size of e budget.

At present these matters are quite speculative, and budget levels are etermined much less objectively. The principal factors are public suport, energetic research leadership, and available revenues. A detailed udy of this question might be a valuable part of long-range research anning.

General Conclusions

The root of fishery problems is people. Selfish interests and narrow ews, imposed on a complex situation involving economic as well as biogical variables, are important elements. Pressures caused by growing

industrialization and increasing human population threaten to outstrip our slowly accumulating stock of basic knowledge. A broad field of inquiry must be pursued if we are to use our marine resources wisely. It would be naive to assume, of course, that with sufficient knowledge and enlightened public policy all these problems would disapepar. Many elements in this complex are mutually antagonistic and always will be. Our aim should be to achieve the best possible combination of circumstances that will serve all human interests. This seems an almost overwhelming task, and the perfect solution never will be found. It follows that controversy always will be an important by-product. Indeed, although our knowledge will increase more rapidly as our support of research on living marine resources grows, public controversy may well increase also as our expanding human population comes into ever more intimate contact with the problems its very growth will generate.

One important deficiency is in the field of public education. Our knowledge of the biological, physical, economic, and social —— political aspects of fishery mangement is far better than many people realize. We are not taking full advantage of our opportunities to improve public knowledge and understanding. For example: we should be putting far more effort into helping the industry to apply our present scientific knowledge of oyster biology. We should establish a shellfish extension service similar to the agriculture extension services on which our highly successful agricultural indutry is based.

When we add the effects of pollution and the other by-products of industrialization and human population growth to the other problems of the oyster industry, it becomes clear that some highly-controlled form of farming is inevitable if the oyster industry is to survive in areas close to civilization. Yet we are still conducting much of our research and management as if virgin conditons will be with us forever. Scientists believe that the time has come to apply accumulated knowledge to develop a higher level of oyster culture.

At our present level of knowledge, little can be done to reduce fluctuations in crab or menhaden abundance. But there is hope that we can apply our knowledge to a system of forecasting, which would allow the industry to plan ahead.

The individual fisherman, with limited capital, is in a very poor position to withstand fluctuations in abundance of wild stocks, even if he should have advance information. The traditionally independent attitude of Chesapeake Bay watermen may not be in their best economic interest. The opinion is given, when a system based entirely on private enterprise is advocated, that this soon would result in control by a few. Undoubtedly this is true, but the individual might be better off financially working for

large fishing company which had sufficient working capital and diversi-cation of operations to hedge its losses. Obviously, these watermen place reat value on their independence, placing it above mere economic gain. n our rapidly changing world, this is unfortunate, for a system of private nterprise seems inevitable if our inshore fisheries are to survive. Recogni-on of this fact now would allow an orderly revision of the structure of shing operations. This illustrates the importance of considering social nd political, as well as economic matters, in applying the results of research o fishery management.

We do not have a very clear idea as to how much should be invested nnually in research on our living marine resources. It is generally agreed iat present research effort is inadequate. As a part of long-range pro-ram planning we should attempt to develop objective criteria for deter-ining budget levels.

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Research And The Oyster Industry

by J. L. McHugh

Chief, Division of Biological Research, U. S. Bureau of Commercial Fisheries

SPECIAL ANALYSIS

Research And The Oyster Industry

by J. L. McHugh

Chief, Division of Biological Research, U. S. Bureau of Commercial Fisheries

A thought-provoking analysis of the relationship between science and industry in the fisheries, criticism of both for failing to adequately meet current shellfish problems and a pointed discussion of ways in which scientific knowledge can be better utilized to aid the oyster industry were contained in a presensation by Dr. McHugh at the 54th Annual Convention of the Oyster Institute of North America in Baltimore recently. Using the Chesapeake Bay oyster industry as an example, "because this is the region I know best," the biologist reviewed the principal problems facing the industry—diseases such as MSX and the oyster blight *Dermocystidium*, lack of understanding of environmental factors, predators, weather and pollution—and efforts that have been made by scientists and the industry itself in meeting these problems. After concluding that these efforts have been far from satisfactory, he went into detail on better ways of applying scientific knowledge, as follows:

I purposely paint a gloomy picture of the practical application of our scientific knowledge of oysters. I do this to develop the thought that our private viewpoints and public policies have been at fault. Let us look at our scientific knowledge from another point of view, from a direction that suggests how this knowledge can be put to practical use.

In previous discussions, I dealt with the principal biological problems of oyster growers from the standpoint of one who would attack them directly. This was consistent with the popular belief that we should solve them by frontal assault, as it were. It is obvious that our extensive scientific knowledge offers no immediate hope of direct control of epidemics of MSX or *Dermocystidium*. Industry has been slow to adopt or even test more effective methods of pest control. Biologists have a great deal of information on spawning, setting, growth, fattening and mortality, among other things, but they have not shown how these characteristics can be altered favorably by direct methods.

In other respects, however, there is a great fund of knowledge that shows how these problems can be attacked indirectly. The Virigina oyster, for example, is an estuarine animal. Under natural conditions it usually thrives best in waters of intermediate salinity. If it survives at all in saltier waters, it usually does so most successfully along the shoreline, where it is periodically exposed by the tides. What does this signify to the oyster planter? As far as Chesapeake Bay is concerned, it means that the upper limit of oyster distribution is determined by its ability to tolerate fresh water. Its seaward limit is set by the tolerance of its enemies and diseases to waters of reduced salinity. The oyster's principal advantage over these enemies and diseases is that it can survive and thrive in salinities that do not drop below five to seven parts per thousand for any considerable period, while its predators such as drills and starfish, and diseases like MSX and *Dermocystidium*, are not a serious problem in waters below 12 to 15 parts per thousand. Extensive areas in Chesapeake Bay lie within these limits of salinity, and this zone includes most of the naturally-producing oyster grounds. Some of this favorable water is unsatisfactory because the bottom is unsuitable, or for other reasons. But much of it could be utilized for oyster growing if local traditions and State laws permitted it. It is significant that in Virginia, for the most part, these favorable zones lie up the estuaries.

Can Science and Industry Communicate?

FISHING INDUSTRY leaders and fishery scientists around the country are expressing a growing realization that there has somehow been a failure of communications between the two groups. Dr. McHugh, as he emphasizes in the accompanying article, is of this belief:

"I have suspected that we do not really understand each other very deeply," McHugh declares, "that we each go our own way pretty much as we please, and that we somehow are failing to help each other as much as we might do."

McHugh and others have proposed an extension service through which the Bureau of Commercial Fisheries could better disseminate scientific knowledge to the fishing industry and assist the industry in the practical applications of this knowledge. Such a service, so far discussed with relation to the shellfish industry only, would be composed of a group of knowledgeable people who would work with industry in developing scientific information and in actually putting it to use. Many prominent fishery leaders questioned by THE FISH BOAT in regard to such a service have been enthusiastic:

"In our present circumstances," one of these men declared, "we must gain and put scientific knowledge to use as quickly as possible. The extension service should be of great benefit in helping us do this. I'm for it. We must work as a team."

"...Traditional Methods...Work Against...Oyster Grower"

The James River seed area and the public bars of the Rappahannock River are examples. In Maryland, on the contrary, a very extensive part of the Bay itself lies between these limits. This, then, suggests one way in which the problem of predators and disease can be solved indirectly. We could grow oysters in areas where these problems are absent. Is the industry taking full advantage of this knowledge? I do not think so.

Your immediate reaction may be—public opinion and policy are against this in many areas, and we are prevented by law from following your advice. My reply is—laws can be changed if public opinion favors change. How can *we* work with *you* to help you take advantage of accumulated scientific knowledge?

SEED OYSTERS

What is probably the greatest single seed oyster producing area in the world is concentrated in a short stretch of the James River. We do not know all the reasons for the great productivity of this area. We do know that it has continued to yield a bountiful harvest each year almost without fail, despite a heavy fishery. Nowhere else in the Bay is such a steady and heavy set of oyster spat obtained. Yet once set, these oysters grow quite slowly. The characteristics that favor spawning and setting obviously do not favor growth.

This very slowness of growth, however, favors this seed for planting in drill-infested waters in the lower part of Chesapeake Bay. Slow-growing oysters are thick-shelled oysters, and drills can penetrate thick shells only with difficulty. This is why an extensive oyster planting industry had managed to develop in the salty waters of the lower Bay, until the recent epidemic of MSX virtually wiped out this operation. If bottoms more favorable for planting, in terms of absence of drills and blight, had been open for leasing, these less favorable bottoms might never have had to be used.

The waste involved in the crude farming techniques employed in the Virginia parts of Chesapeake Bay is startling. I do not have accurate figures for the total numbers of oysters in a bushel of seed from the James River, for these oysters range in size from microscopic spat just recently set to oysters of market size. Because growth rates are slow in the seed area, many ages are represented in the seed harvest. The most abundant of all age groups, naturally, is the group born during the year of harvesting. When harvesting begins in October, these new-born oysters, only about two months old, are very delicate. Probably none survives the multiple perils of damage during harvesting and desiccation on board the tonger's boat and buy-boat before replanting and smothering by mud and silt or predation by drills and other enemies shortly after replanting. This means that at least half of the seed harvested in the James River is wasted.

There are several ways in which much of this waste could be avoided. It might be practical to delay the seed harvest until spring, when these newly born young will have increased to a size more able to withstand transplantation. Survival could be increased substantially if bottoms could be leased in waters of lower salinity. Seed would be used more efficiently if economical methods could be developed to plant cultch in seed areas and transplant the spat each year. Have we done everything possible to solve these problems? I do not think so.

Even the traditional methods of harvesting and marketing oysters work against the best interests of the oyster grower. The old myth of the "R" months has had much to do with this, I suspect. Oystering traditionally begins in fall, shortly after the end of the spawning season. At this time the meats are perhaps at their poorest, thin and watery with poor reserves of glycogen, the animal starch that gives plump oysters their sweet and delicate flavor. Moreover, summer is the greatest period of stress for the oyster in other ways. All biological activity is at its peak. Many oyster pests and diseases are in their most active period. In the saltier waters of the lower Chesapeake, where most planting acreage is located, biologists know that summer mortalities of 25 to 50 percent are not uncommon. This means that, in many years, from one-fourth to one-half the oysters alive on these grounds at the end of June will be dead by October. Moreover, the growth rate of adult oysters slows down in summer. There is very little gain in size to balance these substantial losses by death.

If you were to havest your crop in late spring, about four or five months earlier than usual, you would gain in at least three ways. Your oysters would not be appreciably smaller. You would havest perhaps one and one-third to twice as many bushels. Each bushel would yield perhaps twice as many pints of meats. These meats would be of prime quality, at their fattest and tastiest. It would not be unusual to produce *twice* to *four times* the usual yield of shucked meats by adopting this simple change in harvesting practice. I can hear some of you saying the price would be lower, because demand is poor at that season. This is primarily a matter of tradition, I think. People's habits can be changed, or methods can be developed to preserve these prime meats, for sale when market conditions are at a maximum. Have you done everything possible to take advantage of this knowledge? I do not think so.

HAS PUBLIC MANAGEMENT SUCCEEDED?

In most oyster producing states, the naturally producing grounds have been set aside as public grounds, either to produce seed for planting on barren leased ground, or for harvesting market-size oysters directly. Many states spend considerable sums to protect and rehabilitate these grounds. I think we would all agree that these efforts have not been entirely successful. Combined oyster production of Maryland and Virginia has declined from 22 million bushels in 1890 to less than 6 million in 1961. When oystering began, the entire crop was harvested from public grounds. Now about three-quarters of Virginia's production comes from formerly barren grounds leased to private planters. Many formerly productive public bars in Virginia now are barren. These could be returned to production under private management, but state laws and local traditions are opposed to leasing of public grounds, even if they produce no oysters.

The decline of the Potomac River oyster industry has been well documented. Toward the end of the nineteenth century the total area of productive natural oyster ground in this

river reached the impressive figure of 42 square miles. Today the productive area is only a quarter this size, and yields per acre almost certainly are lower. The newly-created Potomac River Fisheries Commission has the opportunity to create oystering history by taking bold steps to reverse this trend.

THE FUTURE

These matters are far more complicated than I have indicated here. To introduce all the complications in a short talk would hide the point I am trying to make. To stimulate thought and discussion, I am going to make a positive statement that none of you may accept. It is simply this—I believe that if the favorable characteristics of Chesapeake Bay and its estuaries for oyster culture had been used to their maximum, the oyster industry would not be suffering the difficulties it suffers today. Please give this matter some serious thought. The knowledge necessary to establish a rational system of scientific management has been available for many, many years. Tradition and prejudice have prevented maximum use of scientific and practical knowledge.

We could, even today if we were free to do so, revolutionize the oyster industry. Almost anyone in this room could write out a plan. The basic knowledge could be drawn on charts, showing the areas in which oysters can thrive but where their principal enemies and diseases cannot. Other charts might show setting areas, growing areas, and fattening areas. Our knowledge is not perfect by any means; but if all available information were brought together, its extent might surprise us all. Armed with such a compendium of knowledge, an atlas of oystering conditions if you will, we then could draw up a master plan for utilizing these areas to their maximum. We could even make rough estimates of the increases in yield and quality that might ensue, and take a stab at making cost estimates. With such a plan, we could attack the difficult problem of securing general support from all segments of the industry, then from state legislatures. We might be surprised to find that changes are not so difficult to make as we have suspected.

Editor's Note — Dr. McHugh concluded his presentation with a discussion of the need for the atlas of oystering conditions which would bring together the knowledge of scientists and the accumulated experience of oystermen and the need for a BCF extension service for the shellfish industry—a group of knowledgeable people to work with the industry in gathering the information needed to implement the plans he outlined and in continually improving the basic knowledge upon which these plans were based.

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APPENDIX 8

Stocktaking for the New Regime

Dr. J. L. McHugh
Chief, Division of Biological Research
Bureau of Commercial Fisheries
U. S. Fish and Wildlife Service

21st Annual Meeting
Atlantic States Marine Fisheries Commission
September 26, 1962

Introduction

Over fishery resources found within their waters, the individual States have supreme control. This provision of the Federal Constitution is far from an ideal arrangement for efficient conservation and management of our marine fishery resources. This has been recognized by the coastal States and is the reason for the existence of interstate fishery commissions, such as this Atlantic States Marine Fisheries Commission.

This Commission has now come of age, having just completed its 21st year of life. What have you accomplished in the last 21 years? What problems remain to be solved?

Some Commission Accomplishments

Under urging by the Commission, a number of States have acted to adopt uniform laws regulating commercial and recreational resources common to the waters of more than one State. Most of the States have improved their systems of gathering catch statistics, and regular bulletins of landings are published for all but a few States. The joint Potomac River Oyster Commission has come into being, albeit with less authority than would have been desirable. These are matters that this Commission has been urging for many years.

Progress in Research

The Fish and Wildlife Service, designated under the Compact as the primary research agency of the Commission, has undertaken many programs at the request of this Commission. Achievements made under these programs include some of our most productive work. To name only a few, these include the ten-year shad research program, now completed; the very successful work on control of shellfish predators, now reaching its climax; the coordinated hydrographic investigations of Chesapeake Bay, which have led to some substantial advances in our knowledge of estuaries; and establishment of research on salt water sport fisheries by our sister Bureau. These are but a few of the successful programs sponsored by this Commission.

During the same period, the States have increased their research capacity considerably. Changes from 1941 to 1961 were reviewed in detail by Dr. Chestnut last year. It is worth noting that the 15 Atlantic coastal States probably employed no more than 15 marine fishery scientists in 1941. Today the research staffs of the 15 States have increased tenfold. Much of this increase has come about through the efforts of this Commission.

These are but a few of your accomplishments. Any one of you could add to this list. There is little doubt that this Commission has made satisfactory progress toward some of its goals.

Problems for Future Attention

But, lest we become too pleased with ourselves, let us look also at the jobs that have not been done. It is fine to have modern research facilities and competent scientific staffs. We need much more basic information about the biology of the living marine resources and their interactions with their environment and with each other. But some of your most difficult problems are problems that scientific research will not solve. These are the problems caused by people -- the social-political problems that were the principal reason for establishment of this Commission.

Our Expanding Population and Technological Growth

I see these social-political problems as falling into two categories. Foremost in all our minds are those caused by our rapidly growing population, our even more startling development in science and technology, our increasing prosperity, and our expanding industry. These developments bring with them many problems which already have received your attention. I hardly need to repeat them again. They include domestic and industrial pollution, with many new and dangerous innovations, such as insecticides, radioactivity, and detergents. They include a variety of engineering works, dredging, filling, dam and bridge construction, diversion of river runoff for domestic and industrial use, and many others. They include numerous shoreline real estate developments that are completely altering the shape of our coastline in many areas. The scientists will admit freely that they know very little about the effects of these changes upon marine life. The tendency is to view all as unfavorable, and I think it is safe to say that this is generally true. It could be that some are actually favorable, but our present level of knowledge is not sufficient to make such judgments. Any one of these developments can proceed to a certain point with negligible effect upon marine resources. Yet we are not able at present to predict when the danger point will be reached.

A troublesome feature of such problems is that we cannot halt population growth, improvements in science and technology, or domestic and industrial development. These changes develop piecemeal: a factory

here, a 20-acre housing development there, a 5-foot deepening of a river channel somewhere else. Under existing controls on pollution, sewage disposal, and deposition of spoil, none of these is a serious threat in itself. But each adds to the pressure on our natural resources. The need is urgent to add to our scientific knowledge. Advancing civilization does not allow us much time. This is why the Bureau of Commercial Fisheries, with your help, is beginning comprehensive studies of the estuarine environment.

Scientific Research Is Not Enough

But, as I said before, scientific research is not enough. I greatly fear that even with maximum effort we cannot gain a sufficiently deep scientific understanding of the complex forces at work, in time to stem the invasion. Indeed, I doubt that it can be stemmed by scientific facts alone. It behooves us, therefore, to stop wringing our hands helplessly and determine what direct action we can take now to steer these developments in a direction as favorable as possible to marine life.

Zoning Our Estuarine Areas

Last year it was suggested that a system of zoning might be a practical way to solve these problems. The idea is under consideration along the Gulf coast, and in some of our Atlantic coast States. We have a good deal of knowledge already that would be useful for this purpose. For example, the James River in Virginia is an oyster seed area of outstanding importance. It has maintained its capacity to produce enormous quantities of seed oysters despite considerable urban and industrial development. It might be advisable to consider preserving the status quo in this river, to protect this irreplaceable resource. Some other area, with negligible fishery resources, might be zoned for industrial development.

Such decisions will not be easy, for they must have concurrence by all interested groups. They will be arrived at only by compromise, each party giving in one respect in order to gain in another. No matter how wise the decisions, some parties will lose what they otherwise might hope to hold. As a preliminary to final decisions, detailed and difficult scientific, technical, legal, and other studies must be made, and the findings must be correlated. It is not certain that this difficult task ever could be consummated, but this should not prevent us from trying, if we believe it to be the best solution. I would recommend that this Commission give serious thought to making this matter one of your primary activities in the year ahead.

Improving our Fishery Laws

The second category of social-political problems is equally difficult. Yet these very problems pointed up the need for coordinated effort and led to the formation of this Commission 21 years ago. I

SEPARATE

OF A PAPER PUBLISHED BY

THE INTERNATIONAL TRUST FOR ZOOLOGICAL NOMENCLATURE

ON BEHALF OF

THE INTERNATIONAL COMMISSION ON ZOOLOGICAL NOMENCLATURE

This paper contains an application relating to a question of zoologica nomenclature which has been submitted to the International Commission on Zoological Nomenclature for decision. As a preliminary, this paper has been published in the " Bulletin of Zoological Nomenclature ". The volume in which this paper was so published and the date of publication are shown at the foot of the first page of the paper.

2. The object of publishing applications in the " Bulletin of Zoological Nomenclature " is to provide an opportunity to interested specialists to submit comments to the Commission on the action recommended in the applications so published. For this purpose an interval of six months from the date of publication is allowed to elapse before the International Commission starts to vote on any given application.

3. One of the principal objects of the International Trust for Zoological Nomenclature in providing authors with separates (off-prints) of applications published in the " Bulletin " is to secure a rapid and wide distribution of those applications among interested specialists, in order to provide to those specialists an opportunity of commenting upon the applications in question before a decision is reached by the International Commission.

4. Recipients of separates of papers published in the " Bulletin " are therefore particularly requested to furnish their comments on the action proposed as soon as possible to the Assistant Secretary, the International Commission on Zoological Nomenclature, c/o British Museum (Natural History), Cromwell Road, London, S.W.7, England.

LYCHNOCULUS MIRABILIS MURRAY, 1877 (PISCES): PROPOSED REJECTION OF BOTH GENERIC AND SPECIFIC NAMES AS NOMINA OBLITA. Z.N.(S.) 1393

By Giles W. Mead (*Museum of Comparative Zoology, Harvard University, Cambridge, Mass., U.S.A.*)

The applicant here requests the International Commission to reject both the generic and the specific names, each a *nomen oblitum*, which form the binomen *Lychnoculus mirabilis*, proposed by Sir John Murray ("Manchester Lectures"—Science Lectures Delivered in (the Hulme Town Hall) Manchester, series 9, 1877 : 132) for the same series of benthonic fishes collected by the '*Challenger*' which was subsequently given the generic and specific names *Ipnops murrayi* by Dr. Albert Carl Ludwig Gotthilf Günther (*Annals and Magazine of Natural History*, ser. 5, no. 8, **1878** : 187).

2. Of the deep-sea fishes taken by the '*Challenger*', few attracted such immediate and general interest as a series of small fishes which bore unique structures on the head, structures presumed by some to be eyes, but by others, luminous organs. Consequently, these fishes, or more particularly the cephalic organs, received considerable attention prior to Günther's preliminary diagnoses of certain '*Challenger*' species in 1878. Most of the workers who discussed this species before Günther's description of *Ipnops murrayi* prudently avoided the use of a binomial Latin name, and Günther's name, *Ipnops murrayi*, has been used exclusively for this species since its proposal eighty years ago.

3. In 1877, Sir John Murray, during the course of a popular science lecture given in the Hulme Town Hall, Manchester, discussed this "wonderful lamp eye" fish, providing it, possibly inadvertently, with the new generic and specific names *Lychnoculus mirabilis*. This lecture, and the new name proposed there, were published but soon forgotten. It was not known to Günther in 1878, although he must have known of Sir John's interest in this fish, for he named it in Murray's honour. According to the Catalogue of the Library of the British Museum (Natural History) (**3**, 1910 : 1383 ; **4**, 1913 : 1881), the first edition of these "Manchester Science Lectures" is wanting in that library, although the 1883 edition (not seen) is on deposit there. Hence, it seems likely that the publication of *Lychnoculus mirabilis* was unknown to Günther, and save for a footnote reference to the Manchester paper in Murray and Hjort's "Depths of the Ocean" (1912, footnote, p. 687), neither Murray's name nor the paper in which it was published appears to have been referred to since.

4. *Lychnoculus mirabilis* is thus an objective senior synonym of *Ipnops murrayi*, the latter a binomen widely used in both popular and technical publications, a name which represents one of the world's most remarkable vertebrate animals and part of which forms the stem of the universally used family name Ipnopidae. The applicant therefore requests the Commission :—

(1) to reject, as a *nomen oblitum*, each of the following names, for the purposes of the Law of Priority, but not for those of the Law of Homonymy :
   (a) the generic name *Lychnoculus* Murray (Sir John), 1877 ;
   (b) the associated specific name *mirabilis* Murray, 1877 ; the two published in the combination *Lychnoculus mirabilis :*
(2) to place the following name on the Official Index of Rejected and Invalid Generic Names in Zoology : *Lychnoculus* Murray, 1877, rejected under (1)(a), above ;
(3) to place the following specific name on the Official Index of Rejected and Invalid Specific Names in Zoology : *mirabilis* Murray, 1877, as published in the combination *Lychnoculus mirabilis* ; rejected under (1)(b), above ;
(4) to place the following generic name on the Official List of Generic Names in Zoology : *Ipnops* Günther (A. C. L. G.), 1878 (gender : masculine), type-species, by monotypy, *Ipnops murrayi* Günther, 1878 ;
(5) to place the following specific name on the Official List of Specific Names in Zoology : *murrayi* Günther, 1878, as published in the combination *Ipnops murrayi* (type-species of *Ipnops* Günther, 1878);
(6) to place the family-group name IPNOPIDAE Jordan (1923, *Stanford Univ. Publ. Biol. Sci.* **3** : 155) (type-genus *Ipnops* Günther, 1878) on the Official List of Family-Group Names in Zoology.

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QUANTITATIVE SAMPLING WITH THE ORANGE-PEEL DREDGE[1]

The orange-peel dredge is frequently ed in benthological sampling. It offers veral advantages over both the Ekman d Petersen dredges. The Ekman dredge ks sufficient weight for deep-water sam- ng, and does not function properly in nd. The U. S. Bureau of Commercial sheries has used the orange-peel dredge tensively in the Great Lakes, as it is the ly dredge presently available that oper- es in hard clay or gravel.

Quantitative benthological investigations quire a sample from a known area. No evious attempts to determine the sam- ng area of the orange-peel dredge in rious bottom types are known. Henson 954) made a comparison of the sampling abilities of the orange-peel and Ekman dredges. He accepted a diameter of 11.5 in. as representing the circular sampling area of the No. 1 size orange-peel dredge. The area of this circle is 0.72 ft^2. The use of this figure presumes a full sample, and would not be accurate where the penetration was limited by a hard substratum. Henson concluded that the orange-peel dredge samples with a lower variance than the Ekman dredge. He attributed this to a more uniform penetration in a mud bottom. The area sampled by an orange-peel dredge is determined, however, by the depth of penetration of the blades and varies greatly with the bottom type.

A series of samples was taken in the laboratory from a container of sand using a size No. 3 Hayward dwarf orange-peel dredge with a closed diameter of 13 in. and a diameter of 15 in. when open. The depth of

[1] Contribution from the Department of Fisheries d Wildlife, Michigan State University, East nsing, Michigan; and Biological Laboratory, S. Bureau of Commercial Fisheries, Ann Arbor, chigan.

TABLE 1. *Area sampled and volume of bottom material collected at various depths of penetration by a No. 3 orange-peel dredge*

Depth of penetration (in.)	Area sampled ($in.^2$)	Volume of sand ($in.^3$)
1	62	57.75
1	68	43.31
1	63	57.75
1	65	57.75
1	66	57.75
1	67	57.75
2	105	173.25
2	105	158.81
2	99	144.37
2	101	158.81
2	103	158.81
2	104	158.81
3	124	303.18
3	124	303.18
3	124	288.75
3	126	303.18
3	123	317.62
3	125	288.75
4	131	404.24
4	134	433.12
4	131	404.24
4	134	433.12
4	127	404.24
4	132	404.24
5	138	519.74
5	138	519.74
5	138	519.74
5	137	519.74
5	135	519.74
5	139	519.74
6	137	635.24
6	138	635.24
6	138	577.49
6	139	635.24
6	137	635.24
6	138	606.36

sand was varied by 1-in. intervals from 1 to 6 in., inclusive. Measurements were made of the area sampled and the volume of sand collected in each sample.

The surface area sampled by the dredge was determined by placing dry beans on the surface of the sand in a 1-$in.^2$ grid. The beans were aligned on the sand by means of a plywood board with holes bored at every inch. The board was then removed and the beans were pushed down until they were flush with the surface of the sand. In this sampling situation the beans could not be pushed to the side. A grab was then made with the dredge and the number of beans taken was accepted as the actual area

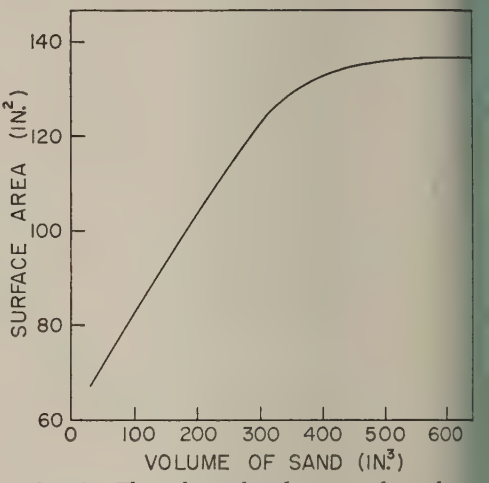

FIG. 1. The relationship between the volume of sand collected and the surface area sampled by a No. 3 orange-peel dredge.

sampled. The volume of sand collected was then measured to the nearest 0.25 quart. The volume data were later converted to $in.^3$. The sampling was repeated 6 times at each succeeding 1-in. depth interval (Table 1). The sand was kept wet throughout the experiments.

The orange-peel dredge covers the maximum obtainable sampling area at a penetration of 5 in., although the volume of material collected increases at greater depths of penetration. A volume of bottom material which measures 520 $in.^3$ or more can therefore be accepted as representing a sample area of approximately 138 $in.^2$ (Table 1).

The relationship between surface area sampled and volume of sand included in the dredge haul was described by the parabola, $A = 51.83 + .338v - .000336v^2$ for surface areas up to the maximum of about 138 $in.^2$. In this formula, A represents the area of the sample, and v the measured volume of sand. The curve shown in Figure 1 can be used to estimate the area sampled from any measured volume of bottom material.

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VARIATION AND CHANGE IN SURFACE SCULPTURE IN ANOMIA ACULEATA

By ARTHUR S. MERRILL[1]

Surface sculpturing on the shell of *Anomia aculeata* Gmelin varies considerably (Verrill and Smith, 1873; Jackson, 1890; Whiteaves, 1901; and Foster, 1937) ranging from smooth to highly spinose. In fact, lacking intermediates, the variants at the extremes could be easily mistaken for separate species. One, accordingly, might expect to find grave nomenclatorial difficulties in the literature but this is not the case. The smoother of the individuals are still occasionally listed with "form" or "varietal" names but it is generally well understood that they are part of a single species complex.

With ample material available, this study was undertaken simply to describe the degree and complexity of sculptural variation normally occurring in this species. As the study progressed I found that spinosity, if it is expressed, develops at widely differing shell sizes. In the usual lamellibranch, a character which develops in the postlarval form becomes apparent at about the same age in all specimens. But in *A. aculeata,* this laboratory has individuals whose variability for the characteristic spinosity may be expressed any time after metamorphosis.

This paper, then, describes variability in *A. aculeata* and presents data to show the change in ratio of smooth to spiny individuals with reference to shell size.

Methods of Collecting and Measuring. Most of the material used in this study came from navigation buoys stationed in offshore waters south of Nantucket, Massachusetts. Since buoys are brought in periodically for cleaning and servicing, the many forms of life found attached can be removed for study. *Anomia* often homesteads the convenient buoy surfaces, after the initial pelagic larval stage, instead of settling in its usual habitat on the bottom. Because smaller *Anomia* were predominant on the buoys sampled, the bottom was dredged to obtain representatives of the larger adult sizes.

A. aculeata usually maintains a suborbicular shape during

[1] U. S. Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries Biological Laboratory, Woods Hole, Massachusetts.

growth. Those which, by some accident of position, meet an obstacle in the immediate vicinity assume various distorted shapes in an effort to circumvent the impediments. This apparently does not affect the morphology greatly other than to shift the axis of growth. The shape may become transversely elongated, or, more commonly, irregularly rounded. Thus, to better indicate true shell size, measurements of both the height and length were taken, added together, and the result divided by 2. Over 4,000 specimens, from newly settled larvae to mature adults, were examined.

Variation in surface structure. A. aculeata derives its specific name from the spinous and/or foliaceous character of its surface. While most individuals exhibit some degree of surface ornamentation, many individuals are entirely smooth. Foster (1937), reporting on specimens brought up attached to shells from fairly deep water on Georges Bank, described considerable variation in the spines, but, lacking smooth individuals, he did not describe this condition. Verrill (Verrill and Smith, 1873) mentioned variations in *A. aculeata* from the Bay of Fundy and the Casco Bay areas and described a variety with the scales "more or less absorptive or even entirely absent." Jackson (1890) and Whiteaves (1901) briefly discussed the smooth form.

Plate 14 illustrates the variation found in the surface sculpture of this species. On individuals with well-developed spines, the spines may radiate to the ventral margin at regular, well-spaced intervals. On others, they may be irregularly or more closely spaced. The spines may be seated on raised ridges or may simply arise from the surface.

Concentric lines form at intervals as the shell grows. The spines terminate at the line formed at the end of each of these growth intervals, and other spines commence to form with renewed shell growth. The degree of fluted, frilled, or other transverse sculpture depends on the degree of development of concentric processes. For example, on those with closely spaced and conspicuous growth lines, the spines are blunted. Often those with weaker growth lines tend to have spines which project from radiating ridges. The spines may also lack radial symmetry and simply form along concentric lines apparently at random over the shell surface.

On those individuals with smooth surfaces, the concentric growth lines are slightly undulate causing the surface to appear craggy or scaly. Very few have the smooth and glittering surface of the allied species, *A. simplex* Orbigny; usually the surface appears dull and chalky.

Practically every conceivable combination occurs between plain smooth and fully scaly individuals. Those not quite smooth may have faint ridges, perhaps just a ray or two in some; others may have a full fan of strong ridges with no sign of spines. On some with ridges, there may be a raised spine here and there, or possibly one of the ridges will be fully spined with none of the other ridges showing the slightest tendency to spininess. Some will be smooth to a certain stage in growth, then suddenly begin producing nicely developed spines. Others may do this and then just as suddenly become smooth again. There is seemingly no end to the possible combinations. For the purpose of this paper, the individuals have been separated into two recognizable categories: those lacking surface ornamentation, and those showing surface sculpture to various degrees. The latter include individuals whose sculpture ranges from faintly rayed to heavily spinose.

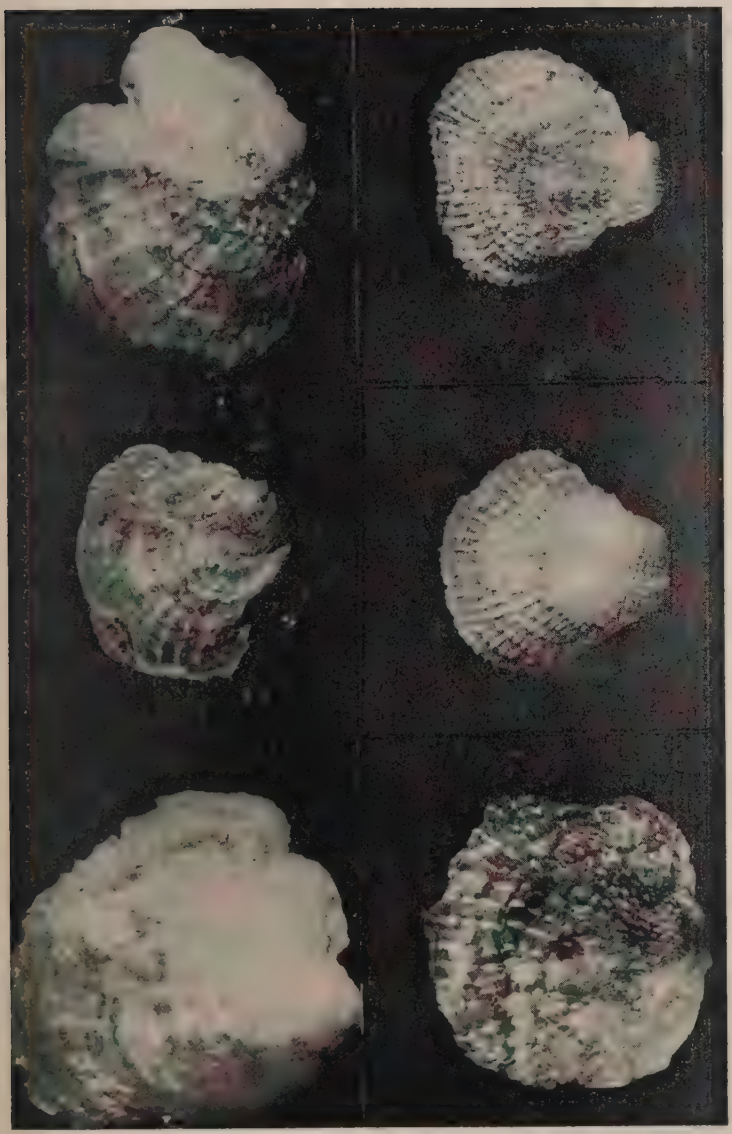
Size-frequency data by station: As mentioned earlier, population samples of *A. aculeata* were taken from 3 offshore buoys as well as from the bottom by dredging. Table 1 lists the frequency distribution from all stations as well as the percentage of smooth *Anomia* in each size category. The station locations and other data relating to them are listed below.

Nantucket Shoals Lightship Buoy (NSLS). The NSLS buoy, located 1 mile, 55° true, north of the permanent Nantucket Shoals Lightship at 40° 33′ N. latitude and 69° 28′ W. longitude, was placed on station October 8, 1957. When removed May 10, 1958, it had been in the water for 7 months. An estimated 25,000-30,000 specimens of *A. aculeata* were attached to the buoy. The sample used for this study consisted of 2,423 specimens.

Davis Shoals Buoy (4DS#1). The station occupied by the 4DS#1 buoy is about 25 miles west-northwest of the NSLS buoy at 40° 57′ N. latitude and 69° 55′ W. longitude. This buoy was on station 1 year from May 7, 1957, to May 15, 1958. The sample taken from this buoy included 537 specimens of *A. aculeata.*

Table 1.--Length frequencies by one mm. size groups and percentage of smooth Anomia aculeata from all stations

	NSLS Buoy		4DS Buoy #1		4DS Buoy #2		Channel		All stations	
Size	No. of specimens	Percentage of smooth	No. of specimens	Percentage of smooth	No. of specimens	Percentage of smooth	No. of specimens	Percentage of smooth	Total no. of specimens	Percentage of smooth
1	132	92.	1	100.	244	93.	--	--	377	92.
2	313	71.	6	100.	409	67.	--	--	728	69.
3	376	62.	3	33.	173	42.	--	--	552	56.
4	439	52.	10	30.	94	32.	--	--	543	48.
5	367	51.	31	16.	35	31.	--	--	433	47.
6	252	52.	50	26.	15	33.	2	50.	319	47.
7	217	42.	50	20.	8	25.	1	100.	276	37.
8	165	46.	64	27.	3	33.	4	25.	236	40.
9	93	36.	67	24.	--	--	14	29.	174	30.
10	49	41.	81	20.	1	0.	11	27.	142	27.
11	14	71.	78	26.	--	--	44	18.	136	28.
12	3	33.	48	38.	--	--	35	23.	86	31.
13	3	100.	28	21.	--	--	33	36.	64	33.
14	--	--	13	31.	1	100.	38	21.	52	25.
15	--	--	5	40.	--	--	32	16.	37	19.
16	--	--	2	50.	--	--	9	33.	11	36.
17	--	--	--	--	--	--	17	18.	17	18.
18	--	--	--	--	--	--	6	17.	6	17.
Total	2,423		537		983		246		4,189	



Anomia aculeata Gmelin. Representative individuals arranged to show variation in shell sculpture.

Davis Shoals Buoy (4DS#2). The 4DS#2 buoy succeeded the 4DS#1 buoy. It remained on station for 6 months from May 15, 1958, until November 10, 1958. The sample included 983 specimens of *A. aculeata.*

Channel Station. At a station about 44 miles northeast of Nantucket Shoals Lightship (41°03′ N. latitude; 68°45′ W. longitude) several bottom tows were made during the course of sea scallop investigations on September 16, 1959. From the dredged material 246 *A. aculeata* were picked from shells, stones, and debris.

Discussion: The larvae of *A. aculeata* pass through a pelagic stage in the upper waters during which time they are subject to variable currents and winds. Hence, they are apt to settle hither or yon in due time on the ocean floor. It is not surprising, then, to find samples made up of individuals that vary from one another widely. Verrill (Verrill and Smith, 1873) observing variation in this species thought it might possibly be a variety of the true *A. ephippium* which has a smooth surface. He was sure it was not *A. glabra [= A. simplex]* of our coast. Whiteaves (1901) remarked of the smooth form of eastern Canada as follows: "The little smooth form of this region that has been hitherto referred to *A. ephippium,* is regarded by Verrill as most probably a form of *A. aculeata.*" Jackson (1890) was able to separate the two species of *Anomia* in our area by means of prodissoconchal characteristics. He found that larval *A. aculeata* had a byssal notch both in the left and right valve, while larval *A. glabra* had a notch only in the right valve. By this means, we all are sure of which species he was referring when he stated, ". . . associated specimens are frequently wanting in the spinous character, although unquestionably belonging to the same species." Bousfield (1958, 1960) followed Whiteaves' lead (personal communication) in listing the smooth form as *A. ephippium.*

Two authors (Jackson, 1890; Foster, 1937) have remarked on the fact that the surface of *A. aculeata* may be smooth for a period of time before spines begin to form. Jackson was referring to the young growing for a brief period of time before any spines were produced; Foster was commenting on occasional large specimens on which the spines were represented only on the outer

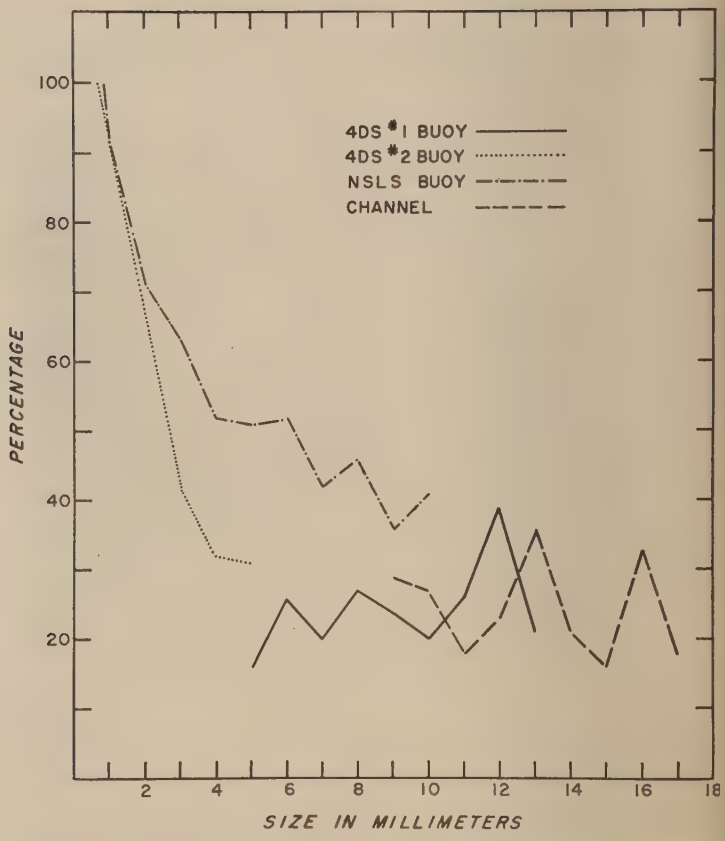


Fig. 1. Data from Table 1 plotted to show decrease in percentage of smooth-surfaced *Anomia aculeata* with increase in shell size.

edge of the shell. These miscellaneous facts can now be connected and a clear picture of variation presented by means of the data.

A. aculeata, in truth, is spineless for a brief period. The first signs of spines appear on occasional specimens at about 0.7 mm. By this time the shell has possibly tripled in height since setting. As can be seen on the graph in Figure 1, the percentage frequency of smooth individuals decreases rapidly at first and levels off at about 25 percent above 8 mm. In large spiny individuals

one can easily trace back along the shell and see when spines were first laid down. Although this usually is found to be within the first few millimeters of growth, as reflected by the graph, it may be found on particular specimens at any size. Even a specimen of almost maximum size may finally express potential to produce spines.

It should be pointed out, in regard to using material mostly from buoys for this study, that the environment on the buoy is probably more uniform than on the bottom. However, the small amount of data from the bottom collections fits in well with the data from buoy samples. This tends to confirm the possibility that variation in surface sculpture in *A. aculeata* might be a genetic rather than an environmentally induced phenomenon.

Conclusion and Summary

1. Surface sculpture in the shell of *Anomia aculeata* varies considerably depending, in part, on size (or age). The surface may be smooth or, to a highly variable degree, spinose. A long series of similarly-sized specimens from single buoy samples can be formed in which graded variability in surface structure is shown easily. Therefore, in keeping with the usual procedures in taxonomy, no distinction should be shown the extreme variants.

2. All early post-larval *A. aculeata* have smooth surfaces and, although a percentage may remain smooth throughout life, many start early to put on spines, the percentage of spiny individuals increasing with shell size.

3. The fact that smoothness is always expressed in the early dissoconch shell implies that spinosity is a natural later development. The early smooth shell undoubtedly represents the generalized or ancestral form. The generalized form found along the western Atlantic coast is *A. simplex,* or along the European coast, *A. ephippium* (type species of *Anomia*). Spinosity, a divergence from the generalized, may be considered a derivative.

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RANGE EXTENSION FOR CYMATIUM CARIBBAEUM WITH A NOTE ON ADVENTITIOUS DISPERSAL

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A specimen of *Cymatium caribbaeum* Cl. & T. was recently sent to me by Mr. Richard Spencer of Charleston, South Carolina. He had collected the example alive from a navigation buoy after it was brought in from its station off Port Royal, South Carolina, to the U. S. Coast Guard Base at Charleston for cleaning and servicing. Clench and Turner (Monograph of the family Cymatiidae in the western Atlantic. Johnsonia: *3* (36): 206, 1957.) record the northernmost range for this species as Lake Worth, Florida. The buoy record thus extends the range northward along the Atlantic coast about 350 miles.

The specimen is a thin-lipped juvenile, height 31.7 mm., width 16.1 mm. This is the second species of this genus whose range has been considerably extended northward as a result of buoy sampling. The first was a juvenile *Cymatium labiosum* (Wood) which I collected in 1948 from a buoy brought in from off Cape Romain, South Carolina. This record appears in the monograph by Clench and Turner (1957) on page 202.

The Cymatiidae are stenothermic and range widely in all tropical waters. A probable long larval stage aids in their wide dispersal according to Clench and Turner. The larvae of the *Cymatium* species found on the South Carolina buoys probably chanced to be dispersed northward from Florida by way of rapid transport in the Gulf Stream. Caught in the coastal waters below Cape Hatteras, they finally settled on the convenient buoy surfaces.

The normal longitudinal distribution of a species with pelagic larvae is controlled for the most part by the temperature extremes that it can tolerate as an adult. The chance dispersal beyond the consistent range of such a species is probably common. When this occurs and when the larvae happen to settle in a favorable habitat during a season in which the temperatures are also favorable, the organisms may survive and grow until such time as

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• Wells, W. Harry and I. E. Gray. The seasonal occurrence of *Mytilus edulis* on the Carolina coast as a result of transport around Cape Hatteras. Biol. Bull.: *119* (3): 550-559, 1960.

the temperature becomes lethal. The fact that an adult of the genus *Cymatium* has never been recorded from the bottom in offshore Carolinian waters suggests that juveniles are winter-killed.

Wells and Gray* recently reported on a cold water species, *Mytilus edulis,* which commonly spreads beyond its normal southern limit at Cape Hatteras. The species is unable to survive summer temperatures in the northern part of the Carolinian subprovince. However, the larvae of the fall spawning colonize this area after the water temperatures fall below lethal values.

There is no need to stress the importance of accurate range records for ecological purposes. In order to increase the accuracy of range records, one must distinguish between that part of the range within which a species is able to maintain itself and propagate, and that portion, usually at the extremes, where it is unable to complete its life history. It is also important to record whether the specimen was alive or dead when collected; especially near the borders of its geographic or bathymetric range. Knowledge of extreme range is particularly useful to indicate possible modifications in the usual biota of an area should long-range environmental changes alter, even slightly, in any direction.

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ABUNDANCE AND DISTRIBUTION OF SEA SCALLOPS OFF THE MIDDLE ATLANTIC COAST

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ABSTRACT

The sea scallop, Placopecten magellanicus (Gmelin), supports a major offshore fishery, principally on Georges Bank off Cape Cod. On a recent cruise of the "Delaware," eight transects were made from Block Island to Cape Hatteras in waters from 20 to 80 fathoms, and 56 additional stations were occupied between the transects. Scallops were taken at over one third of the stations, mostly in depths of 20 to 40 fathoms. At 14 stations, scallops were obtained in commercial quantities (over two bushels per 15-minute tow of a standard scallop dredge).

INTRODUCTION

The sea scallop, Placopecten magellanicus (Gmelin), is most heavily fished on Georges Bank off the New England coast. Over 27 million pounds of sea scallop meats were landed in 1959 to establish a record year. Of this total, 23.1 million pounds (85.5 per cent) came from Georges Bank, 3.2 million pounds (11.9 per cent) from the Middle Atlantic coast, and 0.7 million pounds (2.6 per cent) from other localities.

The Georges Bank region is productive year after year because large areas on the Bank are successfully populated each year. This is probably caused by the closed circulatory system of Georges Bank during the fall months when sea scallops spawn (Posgay, 1950). The current system tends to confine and concentrate the larval scallops on the Bank until they settle to the bottom.

Along the Middle Atlantic coast, the current flows generally to the south with only weak gyrals (Bumpus, 1961). Spawn from any concentration of sea scallops in this area is usually, therefore, swept away from the parent stock. Under these conditions it cannot be expected that any particular ground will maintain a population year after year,

and accordingly the location of concentrations of sea scallops dense enough to support a fishery varies from year to year. When these concentrations occur, the boats converge on them and fish there until the numbers have been severely reduced. This was the case in the spring of 1958 when over a million pounds of scallop meats were taken from an area near Hudson Canyon. Recently over a million pounds were taken from an area off the mouth of Chesapeake Bay which had produced less than 0.6 million pounds during the previous ten years.

Biologists working with the sea scallop have studied intensively the productive region of Georges Bank.[1] In particular, the major beds have been closely followed, and careful attention has been given to yearly fluctuations and changes in stock. However, there has been practically no investigation of the sea scallop stocks of the Middle Atlantic coast. The little information available has been obtained from port interviews with the few scallopers who regularly fish areas off the coast. For a better understanding of the sea scallop fishery it is desirable to know firsthand the sea scallop concentrations along the vast Middle Atlantic coast. Such an understanding necessitates sampling the bottom over a great area. A biological survey was recently undertaken for this purpose and the preliminary results of the cruise are reported in this paper.

METHODS

A recent research cruise (M/V Delaware 60-7, May 11-21, 1960) was designed to investigate the distribution and relative abundance of sea scallops and other invertebrates in relation to temperature and depth along the continental shelf from Block Island to Cape Hatteras. Eight major transects, each of four or more stations in waters from 20 to 80 fathoms, were made across the shelf as indicated in Fig. 1.

1. Block Island
2. Fire Island
3. Barnegat Light
4. Cape May
5. Winter Quarter
6. Cape Henry
7. Currituck
8. Cape Hatteras

1 Reviews of these studies appear in the Bureau of Commercial Fisheries annual reports of the Woods Hole Biological Laboratory for the years 1956 through 1960. Detailed reports are presented at the annual meetings of the International Commission for the Northwest Atlantic Fisheries.

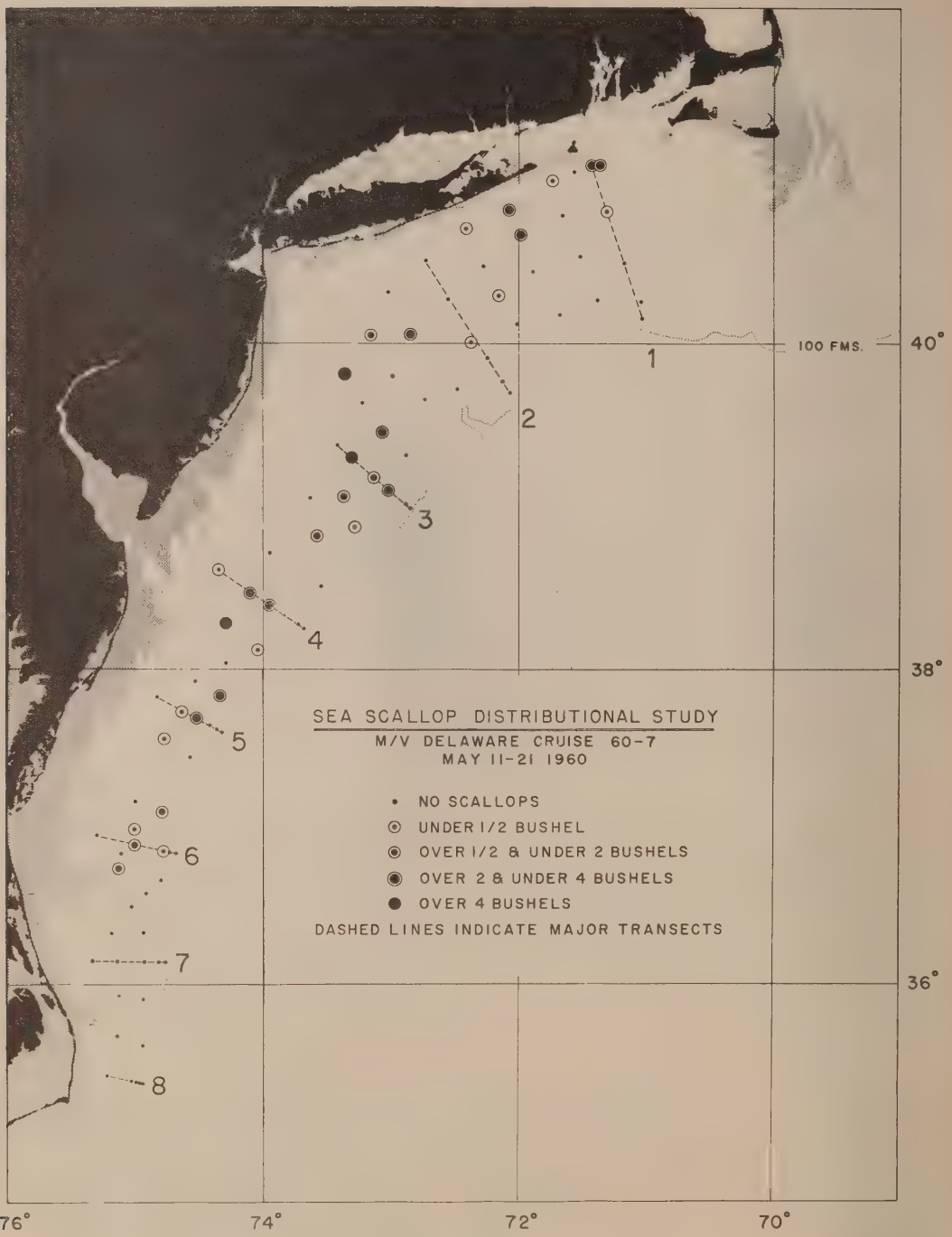

Fig. 1. Chart of the Middle Atlantic Coast showing abundance and distribution of sea scallops. Yield shown in bushels of scallops taken in a ten-foot standard sea scallop dredge with three-inch rings and towed an average distance of 0.94 miles in 15 minutes.

The transects were planned to define the depth limits of scallops. Additional operations could then be confined within areas of reasonable bounds. Fifty-six additional stations were occupied between the transects. In all, 153 tows were taken at 93 stations.

A ten-foot standard offshore sea scallop dredge with three-inch rings and a 30-inch Digby scallop dredge with a half-inch liner were used in dredging operations. The Digby dredge was towed for five minutes at all stations. At all stations along the major transects the standard dredge followed for a 15-minute tow. At stations between transects the character of the bottom, determined by the contents of the Digby dredge, decided the practicability of using the standard dredge. An odometer was usually towed behind the standard dredge. The standard dredge was sometimes towed for more than the usual 15-minute duration to bring more scallops aboard for additional biological data. However, for comparison of densities, all tows longer than 15 minutes have been converted to equal number of bushels per 15-minute tow. The length-frequencies, sex ratios, and condition of gonads of all sea scallops were recorded. Associated invertebrates, fish, and trash were also recorded, and aliquot samples of the dredged material from each station were bagged, frozen, and brought back to the laboratory for future analysis. Certain invertebrates were preserved for identification at a later date. Samples of scallop gonads from selected stations were fixed for histological examination and shell samples of scallops were saved for age reading. Hydrographic operations included bathythermograph casts at each station and at hourly intervals between stations, totaling 174, and the release of 762 surface and bottom drift bottles. All operations were carried out on a 24-hour basis.

DISTRIBUTION AND DENSITY OF SEA SCALLOPS

The stations occupied by the Delaware are shown by circles on the accompanying chart. The relative abundance is indicated by the area of black within the circle. It is based on the number of bushels taken by a ten-foot-wide standard sea scallop dredge in a 15-minute tow averaging 0.94 mile distance as estimated from odometer readings. The symbols are fully explained in the note on the chart.

Sea scallops were taken at 33 of the stations in depths ranging from 16 to 42 fathoms. Fifty per cent of the scallops came from 20 to 30 fathoms, 45 per cent from 30 to 40 fathoms, the remaining 5 per cent under 20 or over 40 fathoms. The best scallop grounds were found to begin about 40 miles southeast of Sandy Hook and to continue below the Hudson Canyon in 25 to 30 fathoms of water. At these depths, scallops were found more or less abundantly south to the Winter Quarter transect.

There were also productive areas of limited extent south to about 20 miles below the Cape Henry transect. The southern limit for live sea scallops was 36° 45' N, 75° 07' W. Small empty valves were found just north of Cape Hatteras (35° 59', 75° 04' W). Sea scallops probably cannot live through summers this far south. Posgay (1953) showed experimentally that juveniles are killed by water temperatures above 23 C. Summer bottom water temperatures in the Cape Hatteras area exceed this.

The best catches of sea scallops were made on sand or sand and pebble bottom containing assorted shell debris. The most commonly associated larger mollusks were Buccinum undatum, Lunatia heros, Crucibulum striatum, Arctica islandica, Spisula solidissima, Volsella modiolus, Ensis directus, Venericardia borealis, and Astarte subequilatera.

The bottom temperatures at the 33 scallop stations averaged as follows:

20 fathoms	50.8 F - 1 station
20 - 30 fathoms	42.2 F - 13 stations
30 - 40 fathoms	41.5 F - 15 stations
40 fathoms	40.5 F - 4 stations

Discussion

As a result of this cruise we now have a better understanding of the present distribution of sea scallops in the Middle Atlantic area. Only three or four of the stations yielded scallops in quantities approaching the density of some of the beds on Georges Bank. However, scallops were obtained in sufficient quantities at 14 stations (Fig. 1) to warrant commercial fishing. No attempt was made to define the limits of the beds during this short cruise.

As mentioned earlier, many scallops have recently been taken from the Chesapeake Bay area. Our dredgings failed to locate scallops in appreciable quantities there even though we checked some of the locations reported as good fishing grounds. Most scallop boats had left this area before our arrival. Apparently a large percentage of the available scallops were harvested before the cruise.

The fishing potential of any area may be predicted one or two years in advance by the number of smaller scallops present. Four such areas that show promise, based on our cruise data, are 50 and 85 miles southeast of Sandy Hook, 50 miles east southeast of Cape May, and 60 miles southeast of Cape May.

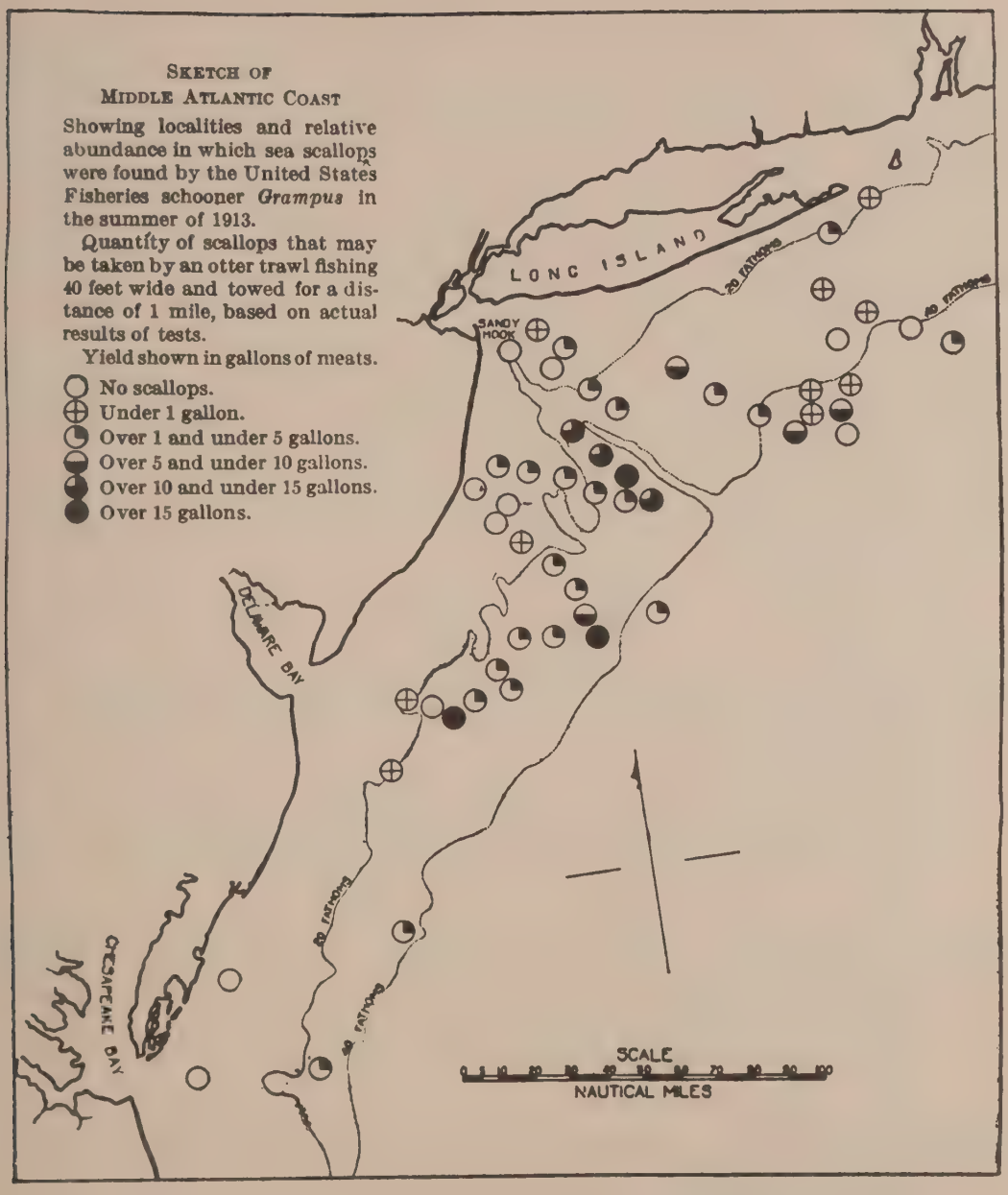
SKETCH OF
MIDDLE ATLANTIC COAST
Showing localities and relative abundance in which sea scallops were found by the United States Fisheries schooner *Grampus* in the summer of 1913.
Quantity of scallops that may be taken by an otter trawl fishing 40 feet wide and towed for a distance of 1 mile, based on actual results of tests.
Yield shown in gallons of meats.
No scallops.
Under 1 gallon.
Over 1 and under 5 gallons.
Over 5 and under 10 gallons.
Over 10 and under 15 gallons.
Over 15 gallons.
LONG ISLAND
SANDY HOOK
DELAWARE BAY
CHESAPEAKE BAY
20 FATHOMS
40 FATHOMS
SCALE
NAUTICAL MILES

Fig. 2. Chart of the Middle Atlantic coast showing abundance and distribution of sea scallops during cruise of the Grampus in 1913.

So far as is known, only one similar investigation has been reported previously. During the summer of 1913 researchers aboard the U. S. Fisheries schooner Grampus discovered sea scallops off the Middle Atlantic coast in enough abundance to interest commercial fishermen (Anonymous, 1914). The small otter trawl used at that time by the flounder fishermen in Cape Cod Bay was advocated, with some modification, for catching sea scallops. This was before the sea scallop industry was established, and before modern gear was introduced. It is interesting to note the similarity then and now of scallop distribution. For visual comparison the chart of the 1913 cruise has been reproduced (Fig. 2). As can be seen, the earlier cruise covered less area than the recent cruise but it did effectively cover the general offshore area from Long Island to Cape May. From the vicinity of Hudson Canyon south to Cape May both cruises show quite similar locations of abundance. However, above the Hudson Canyon the recent cruise found scallops closer to shore, and possibly more abundant. Below the Delaware Bay area the first cruise had too few stations for comparison.

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Freshwater Survival of Pink Salmon at Sashin Creek, Alaska

In recent years, pink salmon (*Oncorhynchus gorbuscha*) have constituted the major part of Alaska's commercial fishery harvest, and it is vitally important that factors controlling their abundance be recognized and evaluated. Although pink salmon have been studied for many years by research workers in Alaska, British Columbia, and Washington, the interaction of these controlling factors is only beginning to be understood.

I will discuss three of these factors which seem to have an important influence on the early freshwater survival of pink salmon at Sashin Creek: (1) Numbers of spawners, (2) time of spawning, and (3) stream gradient.

Sashin Creek is located in southeastern Alaska at Little Port Walter near the southern tip of Baranof Island about 60 miles south of Sitka (Fig. 1). The location, which is on the periphery of the commercial fishery, was selected for studying pink salmon because of the negligible effect the fishery has on fish returning from the sea to the creek to spawn. Therefore, natural marine mortality can be assessed without considering fishing mortality. The assumption of little or no fishing mortality is substantiated by many tagging experiments that have been conducted in adjacent commercial fishing areas of southeastern Alaska. No tagged pink salmon have been recovered at Sashin Creek.

The Sashin Creek spawning area, which is entirely above the influence of tides, covers about 22,000 square yards and is about 1,000 yards in length. Access for salmon to the upper stream is barred by a high falls 1,100 yards above the mouth. The 100 yards below the falls is of negligible importance to salmon because it is steep and rocky and has little gravel. The width of the stream is quite uniform throughout the spawning area. There is no effective intertidal spawning.

Adult pink salmon have been counted annually since 1934 at a weir near the mouth of the creek, and seaward migrating fry have been counted since 1940. On no other stream on the Pacific coast is there a longer continuous record of freshwater pink salmon survival from counted escapements. Presented in Table 1 are the annual escapements,

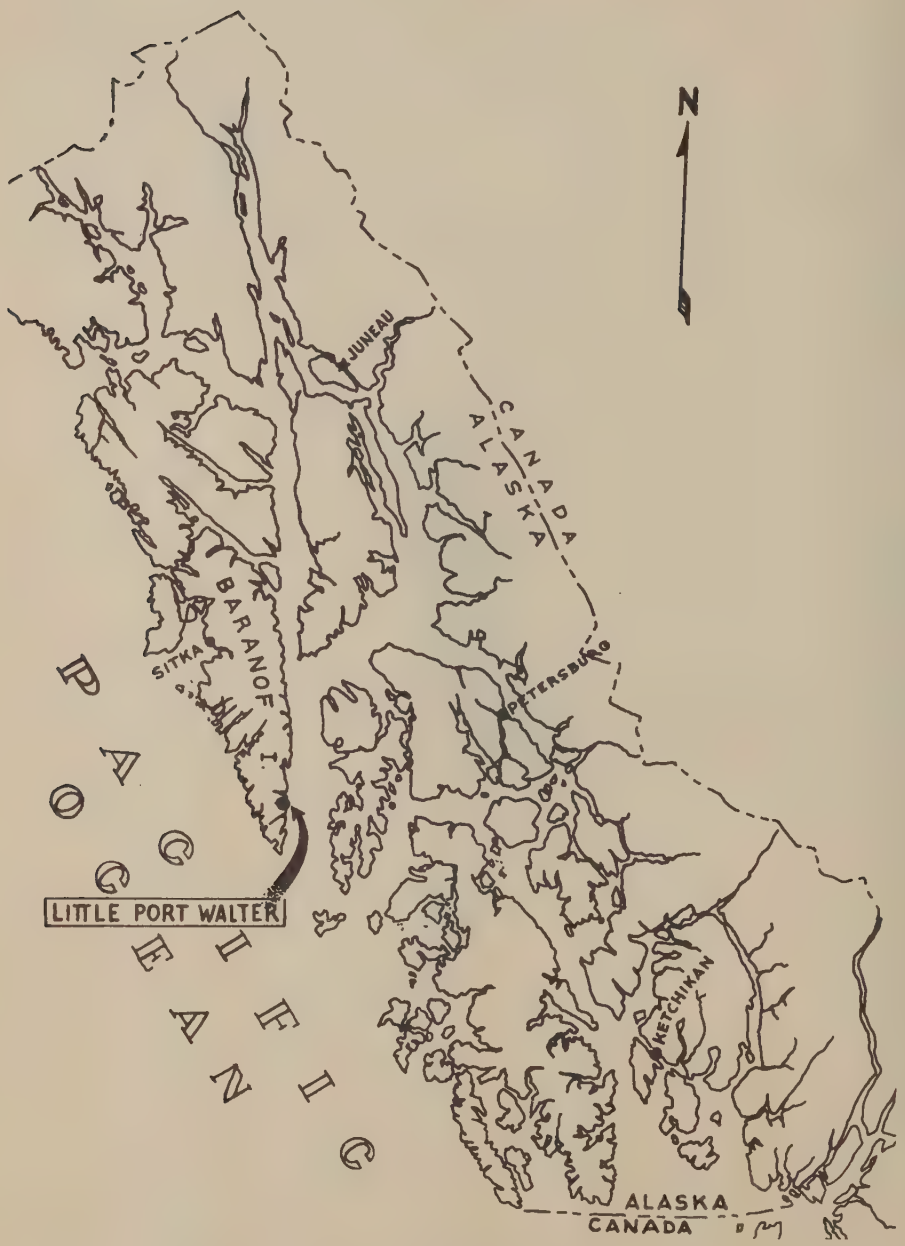

FIGURE 1.
SOUTHEASTERN ALASKA.

potential egg deposition, and survival of fry. Other data that have been recorded and analyzed include air temperatures, water temperatures in the stream and in the gravel, precipitation and stream discharge, and length, weight, sex, and fecundity of adult salmon.

Neave (1953) defines three types of mortality that control survival of pink salmon in fresh water. These are: (1) Extrapensatory, mortality is independent of population density; (2) compensatory, mortality becomes heavier as populations increase in density; (3) depensatory, mortality becomes heavier as populations decrease in density.

The influence of climatological conditions on eggs and fry is an example of extrapensatory mortality. Much of the pink salmon research effort at Sashin Creek has been directed toward determining the relation of stream flow and temperature to survival.

At Sashin Creek climatological conditions are similar from year to year and do not seem to be a major cause of the wide fluctuations in survival shown in Table 1. We have been unable to demonstrate any consistent relationship between survival of eggs and fry and mean air or water temperatures. Even runoff does not seem to have an appreciably consistent effect on survival, although some eggs, eroded from the gravel, have been observed after extreme floods.

An example of the lack of relationship between temperatures and survival may be demonstrated by comparing survival with mean air temperatures during the incubation periods the past 11 winters. Mean air temperatures during the incubation period are shown in Figure 2 and survival in Figure 3. Water temperatures in the gravel correspond to air temperatures, but in a smaller range. Since the winters of 1954-55 and 1955-56 were the coldest during the 1949-60 period, one might expect that survival would have been reduced. Survival of fry during these two coldest winters was very good, however, and was much better than for many of the warmer winters (Table 1). Certainly, temperature is an important environmental influence, but temperature *per se* does not seem to be a controlling factor in freshwater survival at Sashin Creek.

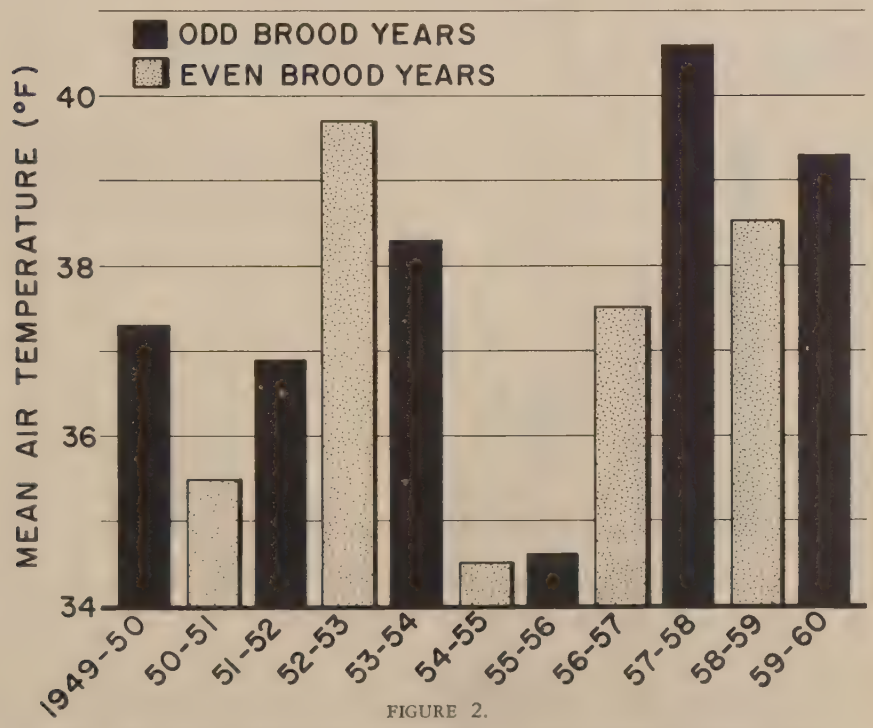

FIGURE 2.

MEAN YEARLY AIR TEMPERATURES, SEPTEMBER TO MARCH 1949-60, DURING INCUBATION PERIOD, SASHIN CREEK.

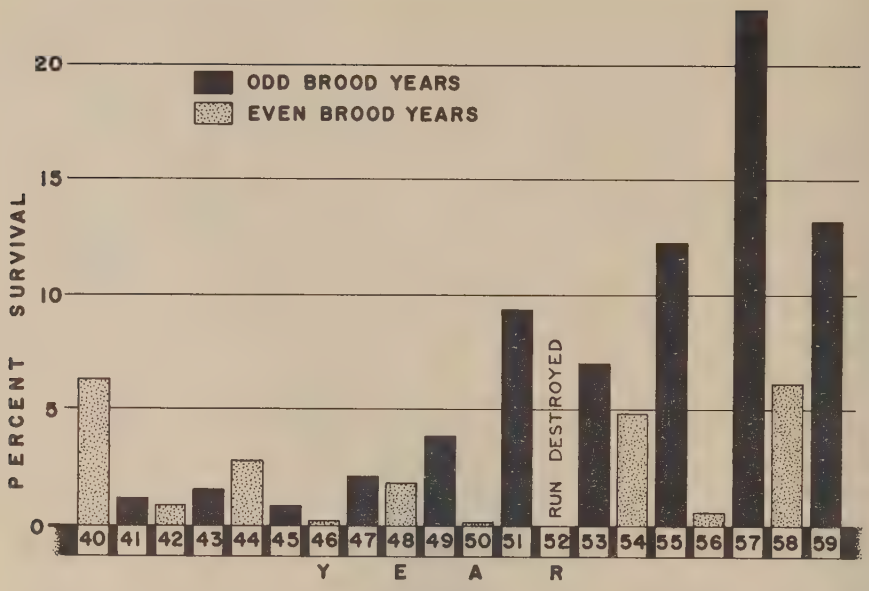

FIGURE 3.

SURVIVAL OF PINK SALMON FROM EGG DEPOSITION TO SEAWARD MIGRATION, SASHIN CREEK.

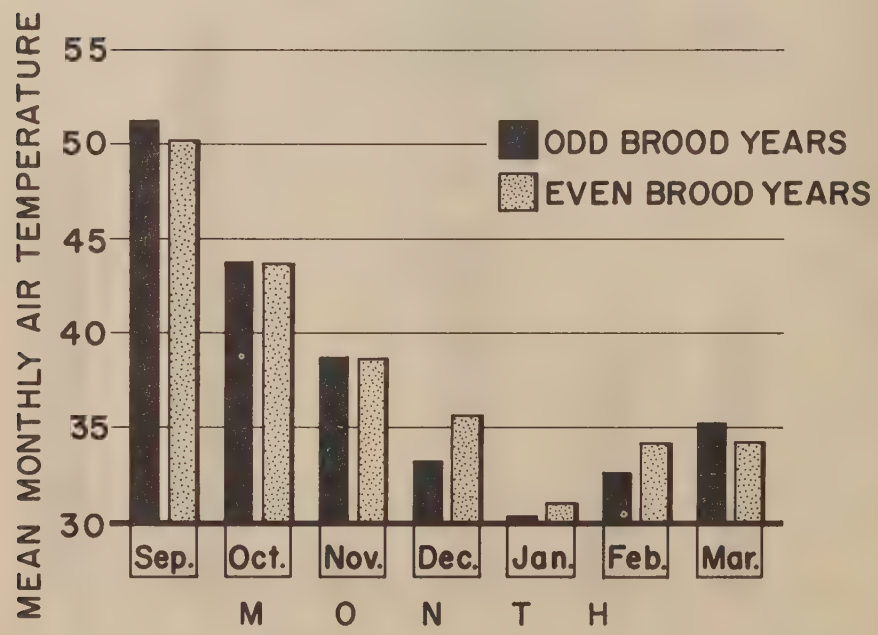

FIGURE 4.

MEAN MONTHLY AIR TEMPERATURES 1949-60, DURING INCUBATION PERIOD, SASHIN CREEK.

The most striking feature of freshwater survival from egg deposition to seaward migration at Sashin Creek is a long-term trend of increasing survival rates for the odd-year runs, particularly in recent years (Fig. 3). This consistent difference in survival of fry between odd- and even-year broods is unrelated to mean temperature differences in odd- and even-year winters, as shown by a comparison of monthly mean winter temperatures of odd and even years (Fig. 4). It is evident from the similarity of odd- and even-year temperatures that winter temperature variations are not the cause of alternate years of high and low survival.

The only difference that has consistently been noted between odd- and even-year runs is that even-year runs spawn later than odd-year runs. This difference was first reported by Skud (1958) whose conclusions were based on data through 1955. Since then, five more years of data have conclusively shown that survival is invariably greater when spawning is early. Fifty percent of the run passed the weir on the average 12 days earlier during odd years than even years (Fig. 5). The most probable reason for higher survival from early runs is that water temperatures are dropping during the spawning season and eggs get a "head start" before cold winter weather retards development during the sensitive period immediately after fertilization. In the even years, when eggs are deposited later in the season, they may be more sensitive to environmental condi-

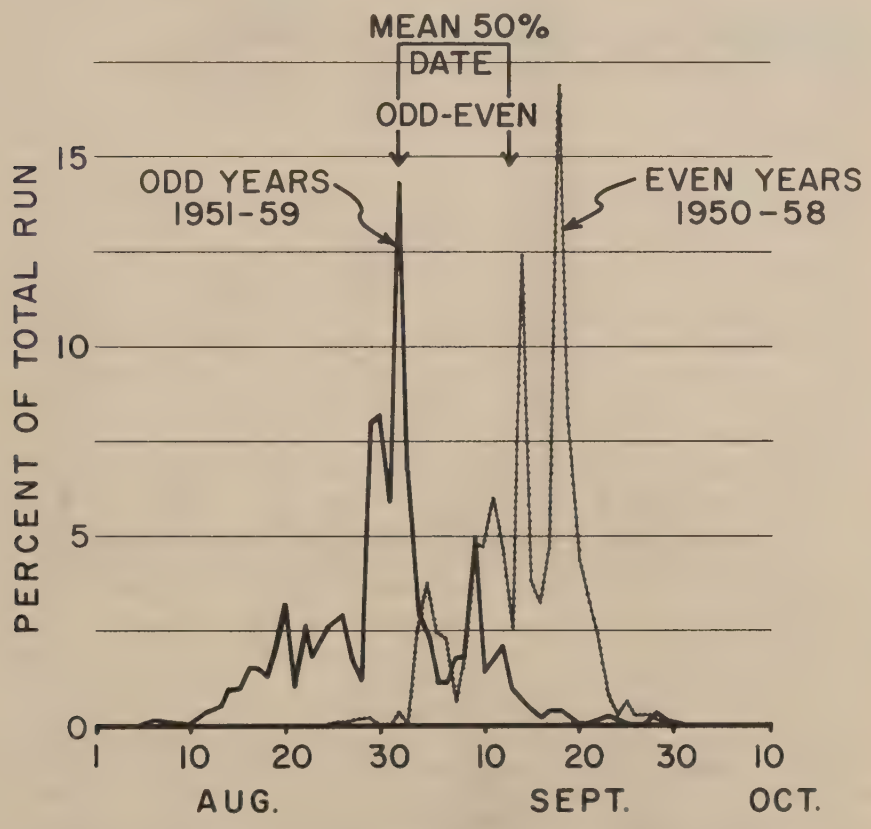

FIGURE 5.

DAILY PERCENT OF PINK SALMON ENTERING SASHIN CREEK, COMPOSITE OF ODD AND EVEN YEARS, 1950-59.

tions, because they do not reach an advanced stage of development before the onset of cold weather.

As pointed out previously, winter temperatures and time of spawning are both associated with extrapensatory mortality in that they are unrelated to numbers (density) of spawners.

The other two types of mortality which affect survival, compensatory and depensatory, are related to numbers of spawners. Since 1934, the numbers of spawners in Sashin Creek have fluctuated widely (Fig. 6). During a 3-year period beginning in the early 1940's, large numbers of pink salmon entered Sashin Creek, reaching a peak of nearly 92,000 in 1942. This was followed by a sudden drastic slump and a long period of low abundance, with the even-year runs almost nil. Then, in 1959 a large spawning run again appeared. This run provided an opportunity to compare spawning characteristics of a large run with the small runs of recent years.

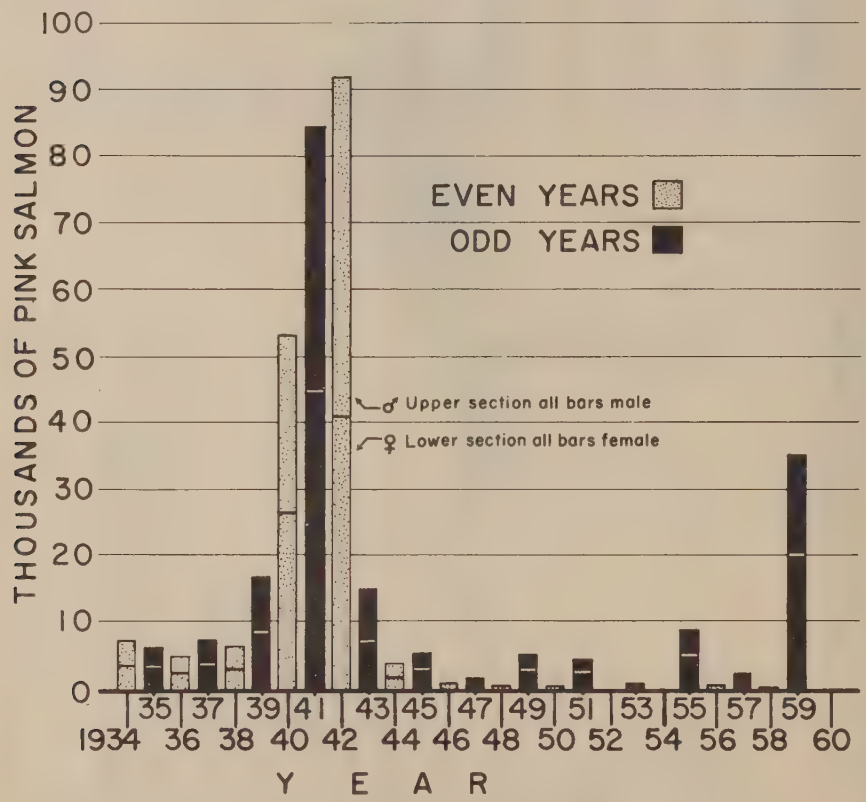

FIGURE 6.
NUMBER OF PINK SALMON SPAWNING IN SASHIN CREEK.

The most obvious difference in spawning characteristics between large and small runs was the distribution of spawning fish. For convenience in locating specific areas, the spawning area has been marked off into 16 sections of approximately equal length (Fig. 7). In recent years, when runs have been small spawning has been concentrated in the lower part of Sashin Creek. This lower part is characterized by moderate gradient, fine

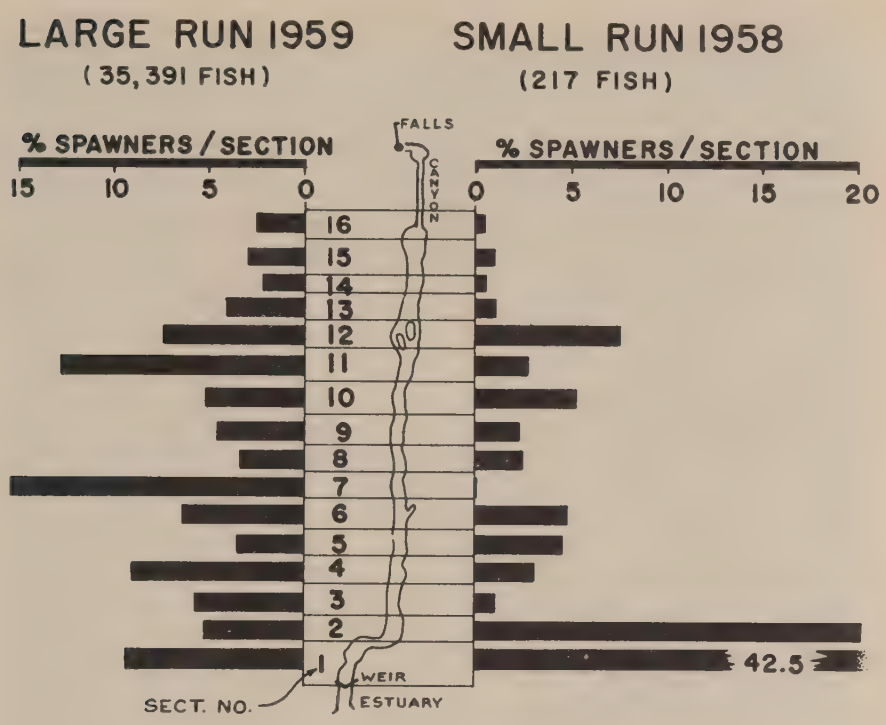

FIGURE 7.

DISTRIBUTION OF SPAWNING PINK SALMON IN TYPICAL LARGE AND SMALL RUNS,

gravel (averaging walnut size), and uniform depth (Fig. 8). This section would appear to be ideal for salmon production. The upper stream, in contrast, has a steep gradient, coarse gravel with many large rocks, and variable water depths, ranging from intermittently exposed bars to deep pools (Fig. 9). The gradient of the lower 700 yards of stream is only about 0.2 yards per 100 lineal yards of stream (excluding bedrock ledges near tide water). In contrast, the upper 300 yards of stream has a gradient of 0.7 yards per 100 yards (Fig. 10). The width of the stream is quite uniform throughout the spawning area, so available spawning areas per unit length of stream are similar.

This difference between large and small runs in distribution of spawners in upper and lower sections was in itself not remarkable and might be expected because of population pressure. However, an additional significant fact came to light in the spring of 1960 incidental to another project. To estimate total fry production from the stream, a series of 303 square-yard areas that were distributed randomly throughout the stream were excavated by pumping a water-air mixture into the gravel. It was found that *the greatest numbers of live fry per unit of area were in the upper steep section where there had been fewer spawners* (Fig. 11). Thus, this upper area was far more productive than the low-gradient section near the mouth of the stream.

The actual causes of this differential survival are unknown, but it seems that gradient, if not a factor *per se,* is at least associated with survival at Sashin Creek.

DISCUSSION

The biological implications of early versus late spawning, high-gradient versus low-gradient production, density, and distribution of spawners are most significant.

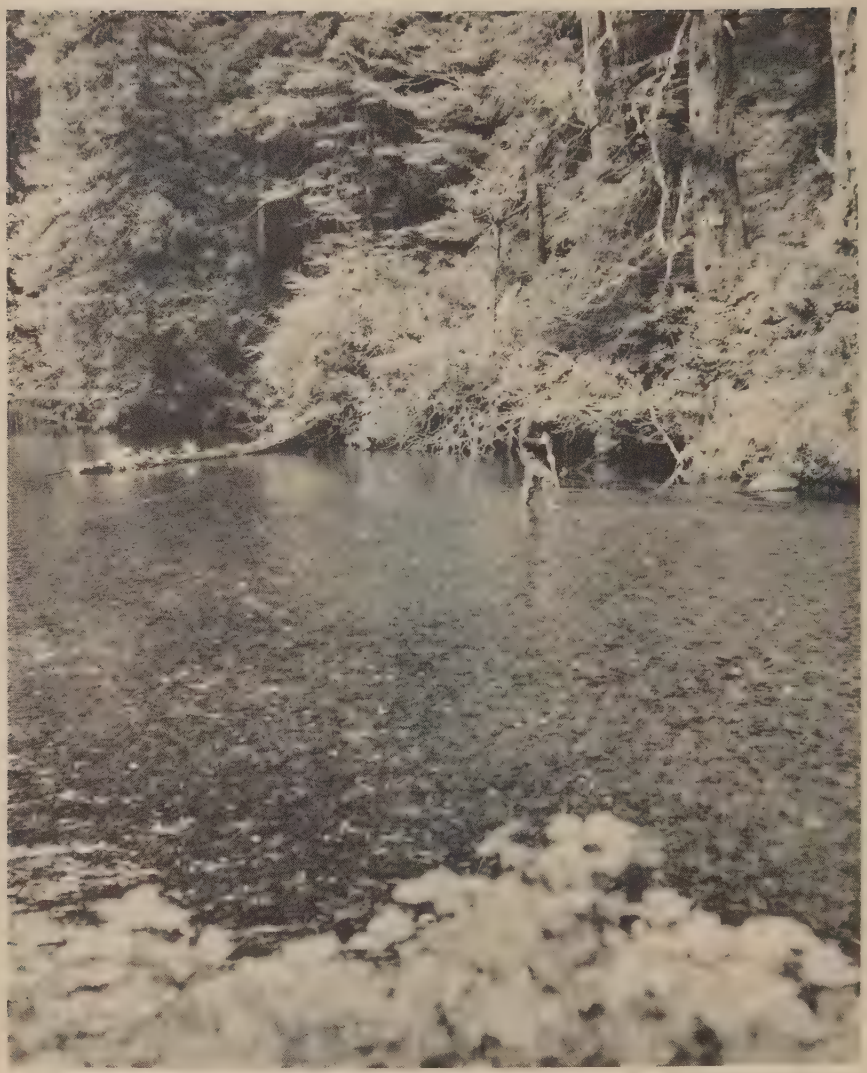

FIGURE 8.

SAMPLING AREA IN LOWER SASHIN CREEK SHOWING MODERATE GRADIENT, FINE GRAVEL, AND UNIFORM WATER DEPTH.

Pink salmon mature at 2 years of age, so runs of alternate years comprise separate races even in the same stream. It is characteristic of pink salmon runs to be alternately large and small in adjacent years. At Sashin Creek in recent years the odd-year runs have been larger than even-year runs, have spawned earlier, and have had higher survival. This has made the odd-year runs inherently more productive than even-year runs and has tended to preserve alternating years of large and small runs.

Furthermore, small runs choose the less productive low-gradient stream areas for spawning, and portions of large runs utilize the more productive high-gradient stream areas. This tends to maintain the numerical differential between alternate large and small runs, augmenting large and depressing small runs.

FIGURE 9.

SPAWNING AREAS IN UPPER SASHIN CREEK SHOWING STEEP GRADIENT, LARGE ROCKS, VARIABLE DEPTH.

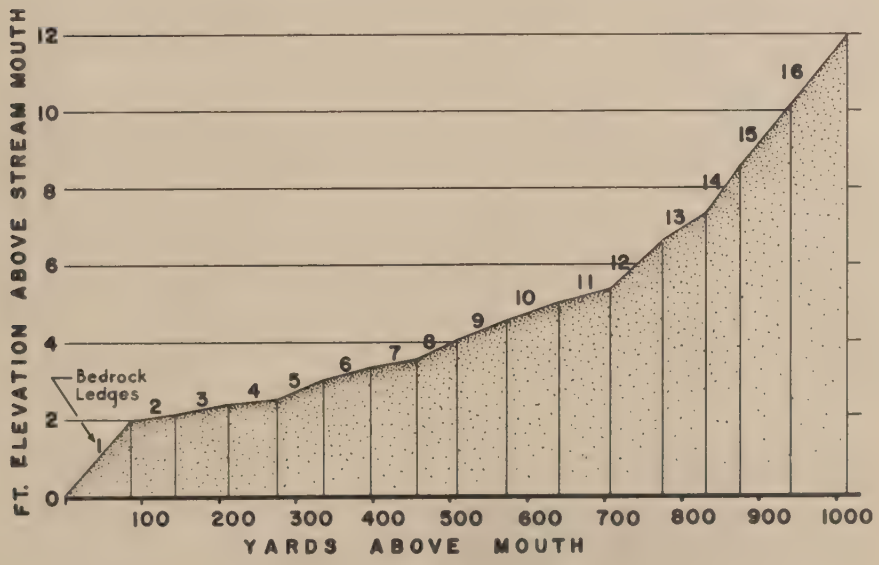

FIGURE 10.

GRADIENT OF SASHIN CREEK SECTIONS.

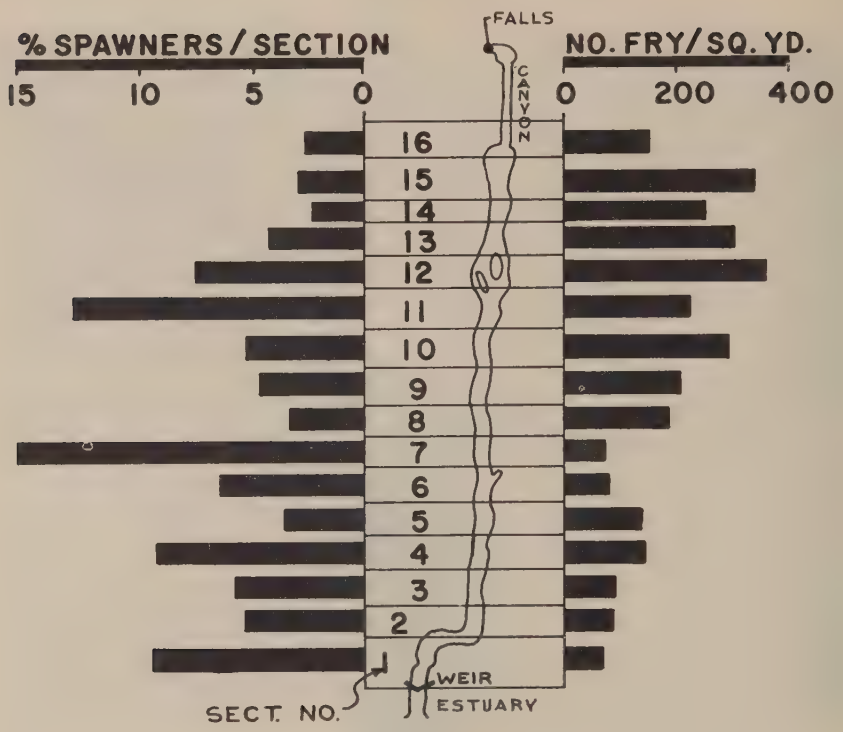

FIGURE 11.

DISTRIBUTION OF SPAWNING PINK SALMON AND RESULTING FRY PRODUCTION, SASHIN CREEK 1959 BROOD.

Depensatory mortality is a characteristic of small runs, and compensatory mortality a characteristic of large runs. If the causes of extrapensatory mortality remain at about the same level (as they seem to at Sashin Creek), there should be an optimum number of spawners, which would result in the greatest actual production of fry.

In all except four years since 1940, fewer than 20 million eggs have been deposited in Sashin Creek (Table I and Fig. 12). The two years of greatest egg deposition had a low survival, similar to that of many of the years of small egg deposition. The 1940 and 1959 runs were intermediate in size and produced the largest number of fry. Somewhere between 20 and 40 million eggs would seem to be optimum. The high survival of the 1957 brood does not seem to fit this hypothesis, but depensatory mortality factors operating on this relatively small run may have been offset by beneficial effects of extremely early spawning. The 1957 run spawned earlier than any other in the past 20 years, and the survival of its progeny to seaward migration was a phenomenal 22.6 percent.

SUMMARY

1. Climatological conditions do not seem to be controlling factors in survival of pink salmon at Sashin Creek.

2. Odd-year salmon runs were found to spawn earlier and produce more progeny per spawner than even-year runs.

3. Survival from egg deposition to fry for odd-year broods has been increasing for the past 10 years.

TABLE 1.

ESCAPEMENTS, FECUNDITY, AND SURVIVAL OF PINK SALMON, SASHIN CREEK, ALASKA, 1940-1959.

Brood year	*Number of spawners*		*Potential* number of eggs*	*Number of fry migrating seaward*	*Freshwater Survival (percent)*
	Total	*Females*			
1940	53,594	26,429	52,858,000	3,402,830	6.4
1941	84,304	44,339	88,678,000	1,024,364	1.2
1942	91,846	40,751	81,502,000	674,672	0.8
1943	14,983	7,490	14,980,000	227,673	1.5
1944	4,050	1,952	3,904,000	104,113	2.7
1945	5,465	2,531	5,062,000	41,900	0.8
1946	933	368	736,000	1,168	0.2
1947	1,486	667	1,330,000	26,454	2.0
1948	597	256	516,000	9,016	1.7
1949	4,902	2,400	4,800,000	176,025	3.7
1950	112	43	86,000	(50 killed)	0.1
1951	4,366	2,031	4,062,000	379,585	9.3
1952			Run destroyed		
1953	1,141	665	1,284,000	90,219	7.0
1954	8	6	12,000	576	4.8
1955	9,241	5,169	10,286,000	1,232,872	12.2
1956	931	509	1,018,000	5,043	0.5
1957	2,612	1,303	2,587,758	588,976	22.8
1958	196	87	174,000	10,577	6.1
1959	35,391	19,981	40,379,327	5,332,468	13.2

*Based on 2,000 eggs per female except when actual fecundity was calculated in 1957 (1,986 eggs) and 1959 (2,021 eggs).

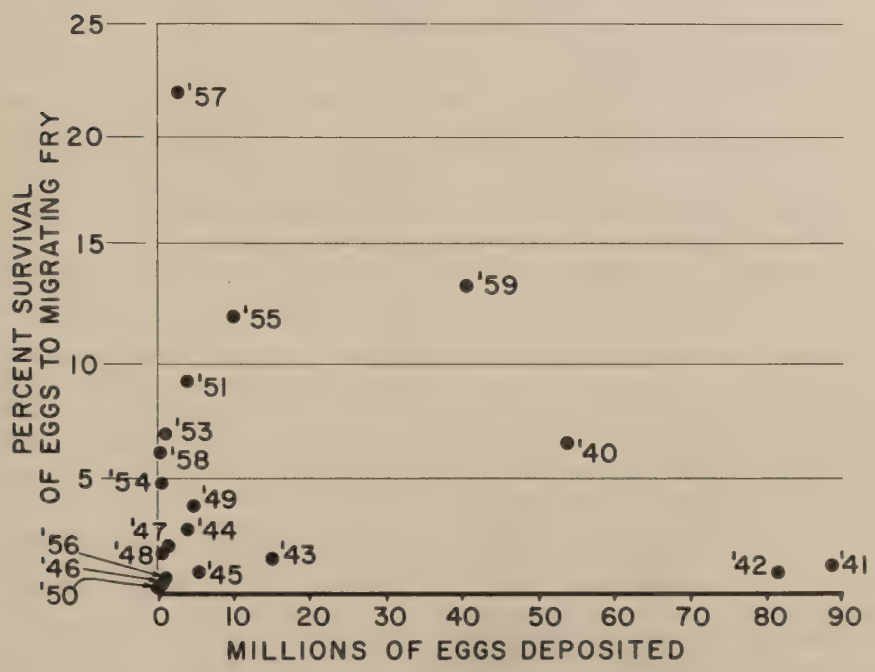

FIGURE 12.

SASHIN CREEK SURVIVAL IN RELATION TO EGG DEPOSITION.

4. Survival is better in steep-gradient stream sections than in low-gradient sections, as evidenced by measurement of fry production from each of the 16 stream sections in the spring of 1960.

5. Small runs do not appear to utilize the more productive steep-gradient sections as extensively as large runs.

6. Both very large and very small runs usually produce fewer fry per spawner than do intermediate size runs.

I do not suggest that these ideas can necessarily be extrapolated from Sashin Creek to other streams, as it is not known whether the same phenomena occur in other areas. Furthermore, some of the hypotheses, such as the relation of gradient to survival, are based on limited data. Much further study to gather comparative data over a wide geographical range and over a long series of years is needed to determine whether these hypotheses are generally applicable.

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DISCUSSION

MR. VERHOEVEN: I couldn't help but wonder about this relationship between the early arrival of the odd years and the tardy arrival of the even years.

You had three graphs that brought to mind some of the things that were mentioned yesterday—namely that timing of these fish to different parts of the stream was not the same. The fish in the intertidal zone, by and large, arrive later than the fish that go upstream. In the graph of the distribution of the 1959, 1958 runs, the fish were not distributed alike. In 1958, the few fish were in Area No. 1 which, on the graph of the stream, looked to me like the intertidal zone, of which there is almost none at Sashin Creek. Your graph of gradient showed that this zone had a very steep gradient; it was unproductive. However, that might be due to the fact that it is an intertidal zone and not just an area of steep gradient.

Next, the graph of the survival of the 1959 brood showed that down in this lower area where all the even year fish had spawned, the survival was very poor. It looks like there is a population factor here that has varied between odd and even years which is just as important as the fact that these fish appear to arrive early on odd years and late on even years.

MR. MERRELL: Actually, the first section is not in the intertidal area. It is above the weir. I don't believe that the tide ever gets up into that area.

MR. VERHOEVEN: My recollection of Sashin Creek is that the area above the weir wouldn't have that gradient.

MR. MERRELL: There are some big bedrock ledges there interspersed with gravel in that first section.

MR. SMITH: You have perhaps drawn a number of conclusions from the discrepant results of your observations on odd and even years. It seems to me that it is extremely important to point out that your even year fish, am I correct, after 1950, are in fact not Sashin Creek fish, and that they owe their origin to other streams?

MR. MERRELL: We were never completely successful in destroying the run. That is true, we don't know where the fish in the even years have come from. There is only one stream with pink salmon anywhere near Sashin Creek, and that is very small. It is about three miles away.

MR. SMITH: My point is that one must be extremely careful in extrapolating this situation to other areas because, in general, we are dealing with odd and even year runs which are native to the particular stream. and this may or may not be the case here.

MR. GILBERT: Do your small odd year runs as well as your small even year runs always spawn in the lower part of the streams?

MR. MERRELL: We didn't keep track of distribution until recently.

MR. GILBERT: These are the only two years you have for comparison?

MR. MERRELL: In the last ten years, the odd years have been larger than the even years.

MR. GILBERT: You have, say, around 1000 or 2000 fish?

MR. MERRELL: The larger the runs, the more they seem to distribute themselves upstream, but we don't have any good way of comparing the very large run of '59. But some of the big years go further upstream than the small runs do. It does seeem to be a function of the size of the run.

DR. RICKER: Have you any idea what caused the low surival of those early runs around the early 1940's.

MR. MERRELL: No. In the largest ones there are written accounts of a severe flood, but we don't—

DR. RICKER: That was only one year, though?

MR. MERRELL: Yes.

DR. RICKER: Another question: Is there any possibility of segregating out the relative effect of early arrival and large population size in accounting for the more favourable survival of the recent odd year? I mean, have you tried a multiple progression or anything of that sort?

MR. MERRELL: I suppose it could be done. We haven't done justice to the data as yet.

DR. TAGUCHI: Have there been any observations on the relationships between the water velocity and egg survival?

MR. MERRELL: Not with water velocity as such. We haven't done that.

DR. NEAVE: You emphasized the relative stability of the envioronment in Sashin Creek, and, in spite of that, you pointed out that there have been wide variations in survival. Do you feel, like the previous speaker, that it is necessary to invoke the marine environment, to explain fluctuations, or do you feel that a large part of it can be explained purely by these freshwater factors?

MR. MERRELL: I personally feel that the early marine factor is very important. We had an inkling of its importance last spring when we found a very heavy predation by herring as the fry were coming out of the creek. That is just one season and one place, and we don't have very much data, but it certainly will bear further investigation.

DR. THOMPSON: Have you made any examination of the relationship of the commercial catch to these statistics? My recollection is that over long periods the odd years will dominate in Icy Straits, that is of the catch as a whole. Then the even year will come to dominate so that there is an alteration of dominance in the runs as a whole. Furthermore, I believe that the regulations varied considerably between those years. I would suggest a close examination of the commercial catch regarding the season. the relationship of the season to your seasons in the odd and even years, and the difference in the regulations during poor years and good years.

MR. MERRELL: We have cursorily examined the commercial catches in relation to the escapements at Little Port and there doesn't seem to be any consistent relation between them. Furthermore, although we know that our assumption is not entirely correct, Little Port is on the very edge of the commercial fishery, and if the salmon come in from the ocean around the southern end of Baranof Island, they would not be exposed to the commercial fishery. However, tagging in Icy Strait, which was the only tagging program anywhere nearby has resulted in recovery of a few fish in the Little Port area. So obviously, some of them come through the commercial fishery.

MR. THORSTEINSON: I might add, too, that the tagging experiments in Lower Chatham Strait, Frederick Sound, have yielded no recoveries into Little Port Walter.

MR. VERHOEVEN: I would like to add a little bit to this question about the effects of the commercial fishery on Little Port Walter. It always seemed to me that if there were a sizeable number of fish coming in the southern entrance of Chatham Strait, there would have been much more emphasis or intense fishing in that area, but instead the fishery has developed in Icy Strait and down Chatham Strait. Tagging as far south as Wilson Cove on Admiralty Island has resulted in recoveries in Little Port Walter. I think that outside of the ways in which the seasons were set for fishing, the fishing can certainly affect Little Port Walter quite severely. They don't come in through an unfished approach.

I had a question to ask you, about the distribution of the fish in the different sections in the creek. In the even years, what is the timing of these fish that go to these upper, or sections you feel give you the better survival?

MR. MERRELL: I don't believe I could answer that. I don't have information. The spawning of the fish does follow closely, with a lag the time of passage at the weir, so that

the weir counts are usable to determine time of spawning. The even years have been so small, and the fish come in in a relatively short time, that there probably wouldn't be any obvious difference between the time of spawning in an even year.

MR. VERHOEVEN: In these years for which you have data, I think you had only 112 fish one year, the first two or three fish might have gone clear to the upper end. They might have been just as early as the earliest fish on an odd-number year, but the bulk of the population arrived late, and spawned downstream in the unproductive section.

MR. MERRELL: It is possible. I couldn't say.

MR. VERNON: In support of your ideas regarding gradient, in Seton Creek we were very much impressed by the survival rates on the spawning ground, and it looks very much like the upper areas of Sashin Creek. Before we knew anything about it, we thought it was very poor spawning ground. It is a mixture of gravels interspersed with boulders, and yet the survival rate apparently is very high.

DR. LINDSEY: I would like to ask either of you why natural selection hasn't favoured in these small runs the fish which go up into the productive area? Why do they persist in staying in the lower area?

MR. VERNON: We don't have that problem.

MR. MERRELL: I don't know. Perhaps it is an example of depensatory mortality, again, which might be a factor in keeping the small runs small. They don't know enough to go up where the survival is best.

DR. RICKER: The farther upstream they spawn, the more fry can get gobbled up on the way down. There is that factor which might counteract.

MR. MERRELL: It certainly could be in some streams. However, predation in the stream, we feel, is relatively insignificant at Sashin Creek. There aren't very many predators, and the distance is short.

DR. VAN CLEVE: How many years' data do you have on the relative productivity of the different sections of this stream?

MR. MERRELL: One. 1959 is the only year.

DR. VAN CLEVE: Don't you think it is rather dangerous to draw conclusions as to relative productivity of the different sections of this stream on even years on one year's data?

MR. MERRELL: We have several years' data on distribution of spawners, but only one on production.

DR. VAN CLEVE: But the numbers involved are so small on the even years, it could be quite significant.

MR. MERRELL: It could be.

DR. LARKIN: Before this discussion is called to a close, I would like to throw in a facetious observation: It seems to me fisheries biology has reached a turning-point. I never thought I would hear a salmon biologist say he had difficulty in exterminating a run of fish.

Through the last two decades, we have had people who have said they did it without even trying.

rly Larval Stages of the Fourspot Flounder, *Paralichthys oblongus*

David Miller and Robert R. Marak

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pp. 454–455
Made in United States of America

(completed in the first 48 hours at 70°F) and the increase in the pigmentation of the eye.

Although the eggs and larvae of the fourspot flounder have been described previously by Agassiz and Whitman (1885, *Mem. Mus. Comp. Zool. Harvard College 14:1–57*), the description has been of little use to subsequent workers because the species was incorrectly designated. Their description was attributed to "The Sienna Flounder" (pp. 32–34) and was figured under the title of "*Pseudorhombus oblongus,* Storer (Pl. XXXI, Fig. 3)," Plates XIV and XV, Figures 1–14. Agassiz and Whitman's figure title is obviously in error. A check of Storer's Plate XXXI, Figure 3 (1867, *A History of the Fishes of Massachusetts, Welch, Bigelow, Dakin & Metcalf, Boston, Mass.*) shows an adult *Platessa quadrocellata* (Storer) which is synonymous with *Paralichthys oblongus* (Mitchill) described here. Until the present studies were made, utilizing eggs of known parentage, it was not possible to ascribe Agassiz and Whitman's drawings correctly. We can now definitely relate their Plates XIV and XV with Storer's Plate XXXI, Figure 3, and ignore *Pseudorhombus oblongus* as an error in caption. Their description and superb color lithographs describing the "Sienna Flounder" agree in every detail with the material obtained by the present authors and recognition of the earlier description is hereby acknowledged.—David Miller and Robert R. Marak, *U. S. Department of the Interior, Bureau of Commercial Fisheries, Biological Laboratory, Woods Hole, Massachusetts.*

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pp. 454–455

EARLY LARVAL STAGES OF THE FOURSPOT FLOUNDER, *PARALICHTHYS OBLONGUS*.—Eggs of the fourspot flounder, *Paralichthys oblongus* (Mitchill), were obtained by artificially spawning ripe male and female specimens taken off Point Judith, Rhode Island, on 9 July 1958. After fertilization, the eggs were brought to the Bureau of Commercial Fisheries, Biological Laboratory at Woods Hole, where they were allowed to develop. Hatching required 54 hours at 70°F. At intervals specimens were removed and preserved in 5 per cent formaldehyde for later examination. Maximum length of survival of the larvae was 102 hours after hatching.

The size of the eggs varies from 0.91 to 1.12 mm, averaging about 1.04 mm in diameter. They contain a single oil globule which is about 0.17 mm in diameter. Both the egg and the developing embryo are colorless until shortly after the formation of the tail-bud at 36 hours. At this time melanophores first appear as minute flecks rather uniformly scattered over the embryo and to a lesser extent, over the yolk mass. Xanthophores appear some 42 hours after fertilization and remain prominent through later development. This yellow pigment appears as rather diffuse blotches whose distribution and density varies widely from specimen to specimen depending upon the relative state of expansion of the chromatophores. This pigment fades so rapidly after preservation that it is valueless as a means of identification and, for this reason, is not further discussed, nor is it indicated in the accompanying illustration. The melanophores, however, are more stable after preservation, their form and distribution commonly being used as identifying criteria.

Directly after hatching the larvae average 2.9 mm in length, ranging from 2.7 to 3.2 mm. The vent opens at the outer margin of the fin-fold and is located nearly halfway back on the body. In common with many of the larval flatfishes, the character of the melanophores in this species varies from specimen to specimen, ranging from rather expansive dendritic forms to small ovoid flecks. Allowing for this variability in the size of the chromatophores, their distribution is very nearly the same for all specimens examined. The melanophores are evenly scattered over the head trunk, and yolk-sac. Halfway between the vent and the tail tip they become slightly more dense so as to suggest a diffuse band extending onto both the dorsal and ventral aspects of the embryonic fin-fold. The remainder of the fin-fold and the extreme tail tip are often devoid of pigment. In this species the general pattern of pigmentation at hatching remains relatively constant during the first 4 days of growth. The only noticeable changes are the gradual absorption of the yolk mass

Fig. 1. Prolarvae of the fourspot flounder, *Paralichthys oblongus*, six hours after hatching. Length 3.1 mm. Illustration by Alice Jane Mansueti.

Extract from PROCEEDINGS OF THE WORLD SCIENTIFIC MEETING
ON THE BIOLOGY OF SARDINES AND RELATED SPECIES - 1959

/II SECTION REPORTS/

REPORT OF SECTION I

Population Identification

Chairman : R. Mužinić
Co-Chairman and Rapporteur : J.C. Marr

1 REFERENCES

Species Synopses : 1, 4, 5, 7, 8, 9, 11, 12
Stock and Area Papers : 3, 4
Methodological Paper 2
Experience Papers : 3, 5, 7, 19, 23, 25

2 DISCUSSION

The problems presented to the fishery biologists are extremely varied. They have included : (a) the discovery of new resources; (b) the discovery of the times and places at which a species can be most readily captured; (c) the explanation of why a particular fishery has changed in some way from a previous condition; (d) the maximization of the quantity (or quality) of the yield of a fishery; (e) the determination of whether geographically separated fisheries are drawing upon a common resource; (f) the prediction of yield; and so on.

What the biologist does to solve a specific problem obviously is (or should be) largely determined by the nature of the problem. Most of the problems, although not all, refer to a particular species, or a group of species 1/. Early in the history of fishery biology it was realized that there were subunits within species, characterized by physical and/or behavioral differences It was believed that these represented self-sustaining population units and a great deal of effort was spent, for example, in characterizing such units on the basis of average vertebral numbers. That is, the biologist was in effect looking to nature to provide some of the same information afforded by a large tagging experiment. Later, it was shown that even though vertebral number is initially inherent, it is modified by the environment. It has also been shown that mean differences between overlapping distributions of meristic characters do not indicate complete independence, but rather lack of complete mixing.

There are two classes of approaches to the problem of distinguishing population units. The first involves recognizing population units by what may be considered marks or tags. Meristic or morphometric characteristics may be so considered when they are unique or non-overlapping. Parasites may be useful as natural tags. Characteristics known to be inherent (e.g. blood groups) may be so used if they are unique. The other approach is based on the use of information and rates of recruitment, growth and natural mortality.

1/ Generally, these problems have not been thought of in terms of ecosystems, for a large number of reasons. Such an approach will undoubtedly be explored more fully in the coming years.

In practice, what determines the necessity of studying population units and, if such stu
are necessary, what dictates the choice of method employed? It is difficult to give general
answers to these questions, since they will not only be influenced by the general nature of the
problem at hand, but also by its unique aspects. On the basis of the record, it appears that
population units have sometimes been studied when knowledge of them may not have been requi
to the solution of the problem at hand. Even when such knowledge was necessary, the most
appropriate methods of study have not always been selected.

If generalizations can be drawn, it seems reasonable to state that in what might be call
exploratory surveys, such as attempts to discover new resources in an area in which fisheries
are already being carried out or surveys of the resources of an area not at present fished, ther
is little point at the outset in attempting to define population units that may exist within particu
species. If the exploratory work is successful and if fisheries do, in fact, develop, the need
knowledge of population units may then arise.

The logical and practical reason for identifying population units is that such units may
their own characteristics of recruitment, growth, natural mortality, migration behavior, etc.
more or less independent of the characteristics of other population units within the same speci
The need for studies of population units in a particular situation may arise from two sources:
there exist variations in yield and/or heterogeneities in the characteristics of the catch for wh
the most likely explanation (hypothesis) is the existence of population units; (b) management
decisions have been made empirically for which it is necessary or desirable to provide under-
standing and thus confidence in the original decisions.

Beyond these general criteria, it is difficult to offer specific suggestions for recognizi
the need for studies of population units because, it may be re-emphasized, each specific situa
with which the fishery biologist may be faced will have its own unique features. It may, howe
be useful to offer illustrative examples of how the need for population unit studies has been rec
nized in specific situations and the rationals of the selection of methods used.

An example of the first kind, variations in yield and heterogeneities in the characterist
of the catch, may be found in the Pacific sardine, Sardinops caerulea. The catch of this spec
has varied widely in both time and space. In addition, some workers interpreted a number of
lines of evidence, including age composition, growth recruitment and migrations (as revealed
tagging) as indicating heterogeneity and thus incomplete mixing. It was not possible to attribu
definitely the major features of the fluctuations in yield (which were the problem of concern) to
fishing. A theory was developed which could explain the fluctuations in yield. In brief, it
states that the fishery is based upon two population units differing especially in migrations and
recruitment. The explanation was suggested by the evidence of incomplete mixing plus the kn
existence of spawning groups separated in space and time (and thus having the opportunity for
etic independence). Since the decline in yield was attributed primarily to a greatly reduced
recruitment of one population unit, the problem of whether the proposed units were truly genet
was of particular interest. Different recovery rates (of the fishery) might be expected, depen
on whether the units were genetically separate or not.

In considering the methods by which this particular problem could be attacked, the mor
metric and meristic approaches were rejected for two reasons. First, owing to the susceptib
of such characteristics to environmental modifications they could not contribute to knowledge c
nature of the units or, necessarily, even to determination of their existence or non-existence.
Second, earlier meristic studies (vertebral numbers) had already been made and did not show

incomplete mixing subsequently revealed by other kinds of data. A tagging experiment was considered in some detail and judged to be the best tool for this particular problem, but was impossible to carry out because of the great expense involved. 2/

It was, therefore, decided to see if the problem could be attacked through the use of characteristics known to be determined by genetic constitution. Blood groups constitute such a character. Though the study has not been completed, the existence of three blood group systems in the Pacific sardine has been demonstrated and two of these systems have proved to be useful. Several samples from several areas have been found to be the same with respect to these characteristics. Recently, one sample has been found to be different.

It is more difficult to cite examples of the second kind from the sardine fisheries; i.e. studies of population units undertaken to provide understanding for empirical management decisions. In the first place, management in some areas has been on a strictly economic basis, such as to prevent additional competition or provide a closed season as a matter of convenience. In other areas, management action has been taken in the interests of conservation but largely on an intuitive basis. Attempts, if any, to understand the effects of the action on populations of sardines have apparently not included studies of population units.

Although there are, as already indicated, many kinds of fishery problems, perhaps the one most commonly posed is how to maximize the yield. For this purpose, it has been proposed that fisheries have to be considered by unit fisheries (resource plus pattern of fishing operations). There is no simple definition of a unit fishery. It is a system constituted by a collection of fish and the fishing activity on it whose effects on each other can be interpreted without requiring information external to that system. A particular group of fish or fishing activities must be included in a particular population unit if fallacious assessments or predictions would be made by their exclusion from it (or, more precisely, if an error of more than acceptable magnitude would probably be made). Biological information requisite to this approach includes rates of recruitment, growth and death. If heterogeneities in these qualities are not evident, the unit has been aptly chosen and will most likely correspond with the population units already discussed. As indicated, one may wish to verify this to provide security of understanding. If heterogeneities are evident, one will certainly wish to investigate the causes of heterogeneity, to see if it is the result of a mixture of population units. If more than one population unit is present, the consequent changes, if any, in management decisions must be based on the extent to which the heterogeneity will affect the original action. In any case, it may be hoped that the two kinds of units will coincide.

Thus, to rephrase and summarize this section, depending upon the general problem at hand, the fishery biologist may or may not be faced with the specific problem of identifying population units. If the population unit problem does arise, it will most likely be evidenced through the existence of heterogeneities, indicating that incomplete mixing is occurring. Decisions must then be made on (a) whether in the specific situation the incomplete mixing warrants further attention, (b) if so, what methods are most likely to provide acceptable results, and (c) what degree of resolution will be regarded as acceptable.

2/ In spite of expense, it must be remembered that tagging is an extremely powerful tool and, moreover that additional information (as on growth and mortality rates) may accrue from tagging experiments.

A somewhat new approach in methodology was also discussed. In addition to the classi approaches to the recognition of intermixed population units, studies of vital statistics (rates o recruitment, growth and natural mortality) may contribute to the understanding of this problem

3 FUTURE WORK

It is hoped that those attempting to identify and determine the structure of population uni will continue to explore the possibilities of other techniques that will constitute powerful new to (e.g. serology, vital statistics, new tagging methods and parasites).

Those who are already involved in such studies are urged to review their research in th light of new approaches. Those who are about to undertake such research are urged to define clearly their problems and seek the most efficient rather than the most expedient approach.

In the selection of characteristics used in population unit studies, care should be taken that the kind of information obtained from a particular characteristic is the kind pertinent to the solution of the problem at hand.

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Observations on the Behavior of Skipjack Tuna, *Euthynnus pelamis*, in Captivity

EUGENE L. NAKAMURA

Maintenance of skipjack tuna, *Euthynnus pelamis*, in captivity for periods up to 5½ months enabled various behavioral observations to be made. Food consumption per pound of skipjack per day when fed to satiation every hour was twice that when fed to satiation once a day. Passage of shrimp exoskeleton through the digestive tract took 1½ hours. The skipjack were conditioned to water slapping as a feeding signal. They did not prey upon small fishes in their pool. Bright blue streaks on the posterior dorsal and dorsolateral surfaces, the white anterior edge of the first dorsal fin, the silvery tongue, and dark vertical bands on the dorsolateral surfaces when feeding are some color features seldom or never observed in dead skipjack. Two size groups formed a single school which was disrupted only during feeding. The skipjack swam with their mouths constantly agape, never stopped swimming, and showed no rheotaxis. Growth from 2 to 3 pounds occurred within 3 months. Recovery from injuries was noted. Causes of mortalities were undetermined, but an inadequate diet was suspected.

ECENT attempts to establish skipjack tuna, *Euthynnus pelamis* (Linnaeus), captivity for experimental purposes have sulted in the maintenance of this pelagic ecies in a pool for as long as 5½ months. wo lots of skipjack, four 6-pounders and ne 2-pounders, were captured at sea on a ole and line and transported in a portable nk to a pool on shore at Kewalo Basin, onolulu, Hawaii. The circular pool was feet in diameter, 4 feet deep, and was led with salt well water. It was illuminated night by a 150-watt floodlight mounted 7 et above the water level at the edge of e pool. Observations on feeding behavior, lor, swimming and schooling behavior, owth, and injuries and mortalities of the ptive skipjack were made. These are beeved to be the first such observations, for is species has not been kept before in capvity for more than a few hours (Tester, 52a).

FEEDING BEHAVIOR

Attempts to induce the skipjack to feed et with little success during the first eight ays. On the ninth day, the fish began to ed on shrimp flesh, and thereafter they ere maintained on a diet of shrimp, squid, id fish.

The skipjack were fed once a day, but casionally additional feedings were given. ood was offered until they were satiated. The average food consumption was 1.6 ounces per pound of skipjack per day.

On 9 June 1960 a feeding experiment was begun at 0640 to determine how much food would be consumed during a day. Food was offered every hour until the fish no longer ate. Four skipjack, each weighing approximately 3 pounds, ate a total of 39 ounces of shrimp over a period of 13 hours. The fish had been deprived of food for 14½ hours prior to this experiment. A repetition of this experiment on 16 June, after a food deprivation period of 21 hours, gave essentially the same result (Fig. 1). In both experiments there was an initially high consumption followed by consumption of small amounts throughout the day. All interest in food was lost at the onset of darkness in both cases.

Information on the rate of passage of ingested items through the digestive tract of skipjack was obtained during these feeding experiments. Fresh fecal material, which was in the shape of an oblong pellet 3 to 4 cm long, was readily identifiable. Because the skipjack tended to swim leisurely along the wall after they were satiated, the fecal pellets could be seen and identified by walking around the pool and scanning the bottom near the wall. Undigested exoskeletons of shrimp were easily recognized in these pellets. After two weeks on a diet of squid,

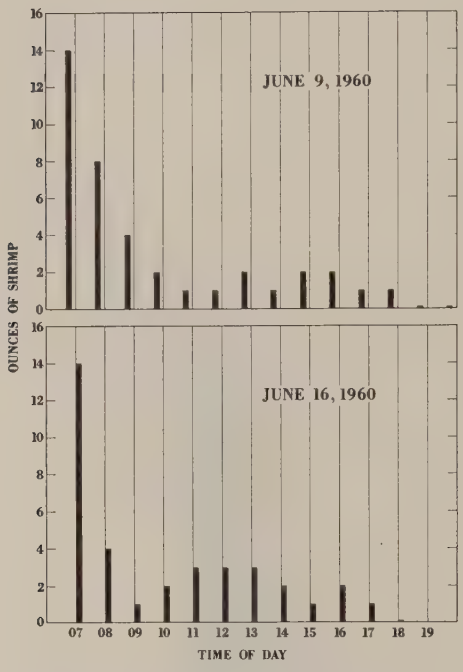

Fig. 1. Amount of food eaten at hourly intervals during daylight hours by four 3-pound skipjack tuna, *Euthynnus pelamis.*

the fish were first fed pieces of shrimp at 0640 on 9 June. The first fecal pellet was observed at 0805. It contained shrimp exoskeleton. Thus, the exoskeleton took 1 hour and 25 minutes for its passage through the digestive tract. The passage was noted again on 16 June, at which time the evidence appeared 1 hour and 23 minutes after feeding. On the two days preceding the latter experiment the skipjack had been fed squid. The water temperature at 0710 on 16 June was 74°F.

Attempts to feed skipjack at night were made on two separate occasions. Food was ignored during the first attempt. On the second, a few pieces of shrimp were eaten. The fish exhibited some difficulty in seizing the pieces, probably owing to the low level of illumination provided by the floodlight at the edge of the pool.

Apparently tuna are able to learn to feed in captivity by observing others. With *Euthynnus yaito,* Tester (1952a) noted that ". . . once a school had been established, new fish started to feed during the second day in confinement." Similar results were obtained in this study. Of the nine skipj in the second introduction, two began f ing on the second day. By the fourth day, were feeding except one whose left eye been badly injured by the hook w captured.

To condition these fish to a feeding sig the surface of the water was manu slapped prior to the offering of food. On third day after the skipjack were indu to feed, they began to respond to the w slapping. By the fourth day they were d nitely conditioned. If the fish were on opposite side of the tank, they would de from their usual circular path to mak dash towards the source of slapping. If t had just passed the observer, they wo immediately turn about.

The fish also associated observers w food, for they would swim immediately to pool's edge where the observer stood. If fish were not fed, they would soon revert their circular swimming path along periphery of the pool. Slapping of the wa at this point would evoke an immedi response, but only when the fish were hung When satiated, the fish ignored water s ping and observers.

In addition to excited swimming behav during feeding, which resulted in disrupt of the school, the skipjack exhibited a patt of alternating light and dark vertical ba on their dorsolateral surfaces (Fig. 2a). T appearance of these bands could be elici by slapping the water. They would appear when the fish were no longer in ested in food.

Food particles were always taken at surface or in midwater, never off the bott The fish often accelerated their swimm just before taking pieces of food.

Selectivity with respect to the size of f particles seemed to increase with the deg of satiation. When hungry, the skipjack t whole shrimp or whole squid, but after gesting a few such pieces, they refused f ther offerings of the same. If the rejec pieces were retrieved and cut into seve smaller pieces, they were readily accept Another behavior exhibited by these f was their aversion, as they neared satiati to chunks of shrimp flesh with the sw merets still attached and heads of squid w the tentacles still attached. When retrie and the swimmerets or tentacles remov the pieces were accepted.

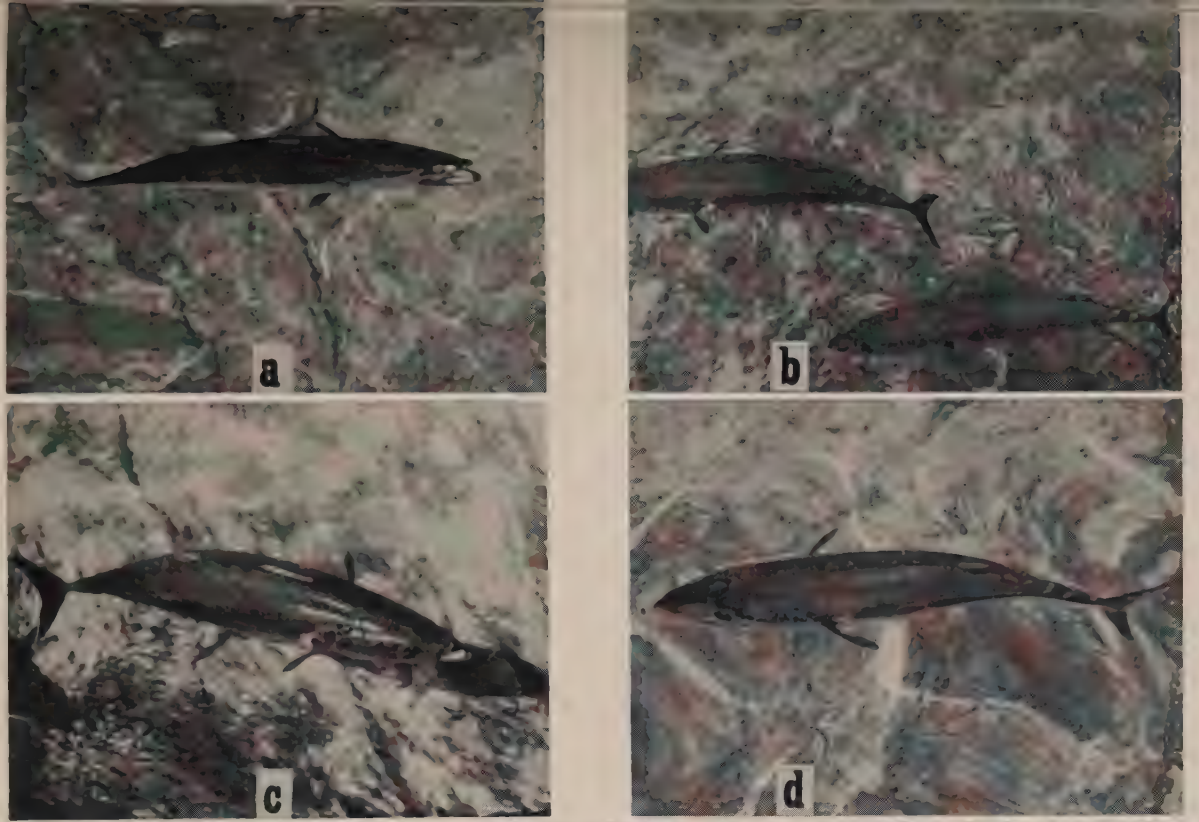

Fig 2. Color features in living skipjack tuna, *Katsuwonus pelamis*. a. Light and dark bands on the dorsolateral surface. b. Blue streaks on the scaleless portions of the posterior half of the dorsal and dorsolateral surfaces. c. Reflection of sunlight from the silvery tongue and axilla of the pectoral fin. Note also the white anterior edge of the first dorsal fin. d. The "pineal window" in the middorsal region of the head.

Small fish are an important portion of skipjack food in their natural environment (Hotta and Ogawa, 1955; Ronquillo, 1953; Tester and Nakamura, 1957; Welsh, 1949), yet the captive skipjack were never observed to prey upon the small fishes which were present in the pool. *Tilapia mossambica* had been held in the pool prior to the introduction of the skipjack and several still remained. A small school of nehu, *Stolephorus purpureus,* and seven threadfin shad, *Dorosoma petenense,* had been offered as live food for the skipjack as an inducement to begin feeding. They were refused and subsequently became established. After several weeks, these small fish became so accustomed to the presence of the skipjack that they showed no fear of their potential predators. The threadfin shad were often seen schooling with the skipjack, and the tilapia sometimes competed with the skipjack for the food that was thrown into the pool. The skipjack always departed from their swimming course to avoid colliding with a tilapia. The tilapia, however, were never observed to get out of the way of an oncoming skipjack.

Color Features

The dorsal and dorsolateral surfaces of the fusiform body of a skipjack are dull blue, while its ventral and ventro-lateral surfaces are dull white. On the lateral and ventrolateral surfaces posterior to the pectoral fins there are usually four dark lateral stripes, which converge near the caudal peduncle. These are the color characteristics that are readily observable in both living and dead specimens.

Several additional features are observable in living skipjack which are seldom or never observed in dead specimens. On the scaleless portions of the posterior half of the dorsal and dorsolateral surfaces is a series of bright blue streaks (Fig. 2b). The pattern of these streaks may differ from specimen to specimen and even from right side to left side on the same specimen. There are usually seven or eight vertical to oblique streaks, the three most posterior streaks usually extending to the middorsal ridge. A lateral blue streak of the same color and approximately of the same width runs slightly dorsally to the longitudinal axis and unites with the ventral ends of any one or several of the vertical streaks. Another lateral blue streak lies just below the middorsal ridge and extends from a point anterior to the second dorsal fin to about t fourth dorsal finlet. It intersects several v tical streaks. These blue streaks in livi skipjack are so bright that they appear to luminous. In dead specimens they lose th brightness and become inconspicuous.

Another color feature seen in living ski jack is the white anterior edge of the fi dorsal fin (Fig. 2a and c). In dead skipja this fin is usually completely retracted in a groove in the middorsal ridge.

Also very conspicuous in living as well in dead skipjack, particularly when sunlig is reflected by it, is the silvery tong (Fig. 2c), which has the appearance having been coated with mercury. In ad tion to the tongue, the axilla of the pecto fin is also capable of reflecting sunlight.

The appearance of light and dark vertic bands on the dorsolateral surfaces duri feeding has been mentioned above. The bands have also been observed in skipja during live-bait fishing at sea from an und water observation chamber (Strasburg a Yuen, 1960; Strasburg and Marr, 1961). T widths and numbers of bands vary from fi to fish. Their prominence appears to be d pendent upon the degree of excitation the individual during feeding.

The "pineal window" can be seen as elliptical spot in the middorsal region the head (Fig. 2d). It has been describ and its possible function discussed by Riv (1953).

Swimming and Schooling Behavior

Although skipjack tend to school by si in the ocean (Brock, 1954), the two si groups in the pool formed a single scho Disruption of the school occurred only du ing feeding.

The skipjack usually swam leisurely arou the pool's edge with the pectoral fins slight extended, the first dorsal fin and pelvic fi retracted, and the caudal fin vibrating. T second dorsal and anal fins were direct posteriorly at about a 30° to 45° ang whereas at maximum extension they we at approximately a 60° angle. Whenev the direction of swimming changed, the fi dorsal fin was erected and the pectoral fi extended. If sudden deceleration was nec sary, all the fins were extended, includi maximum extensions of the second dors anal, and ventral fins.

Skipjack swim with their mouths co

tly agape. This provides a constant sup- of water over their gills. Respiratory ements with the operculum were never erved, nor were these fish ever seen to swimming.

t night the skipjack swam slowly about perimeter, often with the sagittal plane their bodies normal to the light rays from floodlight. Only once were the fish erved at night without the floodlight. On occasion, moonlight was sufficient to w the fish to be seen. They remained a school and swam slowly around the pool. o preference for a clockwise or a counter- kwise direction was noted. Creating a kwise or a counterclockwise current made apparent difference, for the fish went h the current as often as against it.

Growth

Because skipjack in the ocean tend to form ools in which the individuals are all of same size (Brock, 1954), an estimate the size of the captive fish at the time of ture was obtained by measuring a sample m the same school. Weights were obtained m a length-weight formula (Tester and kamura, 1957). Information on growth s obtained by comparing these data with lengths and weights attained by the time death.

No appreciable growth occurred in the ound skipjack. However, the 2-pound pjack gained 1 pound within 3 months. further growth was detected during the maining 2½ months that these fish were ld. Growth from 2 to 3 pounds by skip- k has been postulated to take about 2 nths and growth from 2 pounds to ap- oximately 6½ pounds to take 5½ months Brock (1954). (Length in the skipjack wth curve presented by Brock was con- rted into weight by the formula referred above.) Thus, the two sets of data are in neral agreement for the portion of skip- k growth from 2 to 3 pounds. Limitations space or diet may have contributed to retarded growth beyond 3 pounds.

Injuries and Mortalities

Initial attempts to establish skipjack in the ol were unsuccessful. Capture, transport the bait wells of the vessel, and transfer the pool involved a considerable amount manual handling. Discoloration from the rmal blue to black on the dorsal and dorsolateral surfaces of the fish developed wherever the outer coat of mucus had been rubbed off while the fish were being handled. An inverse relation appeared to exist between the amount of discoloration and the length of survival in the pool. Fish which had been handled never survived for more than 2 days. Many became extremely excited, bumped into the wall, and died within a few hours.

Successful transfers were made with a portable steel tank (Fig. 3) which eliminated manual handling. Immediately after they were hooked, the skipjack were lowered into the tank. The line was then slackened to allow the fish to shake the barbless hook out of its mouth. In port the tank was lifted off the vessel and lowered into the pool. The side hatch cover was then opened and the fish allowed to swim out. The two lots of fish transferred in this manner did not exhibit the discolorations due to handling and were not as excitable as previous lots.

Of the first lot of four 6-pounders, two died within a week, the third about a month later, and the fourth 73 days later. Of the second lot of nine 2-pounders, the first mortality occurred a week after capture and the last occurred 5½ months after capture.

Attempts to determine causes of mortality were made for each fish that died. Many of the fish had eaten heartily the day before death occurred, and were apparently in good health. Examination of gills and internal organs revealed nothing unusual. The only peculiarity found was a pinkish-gray color of the flesh in fish that had lived in the pool for several weeks. The normal color is a deep red. This discoloration of the flesh suggested an improper diet. A change in diet to beef liver was decided after a trial feeding had shown that skipjack would eat beef liver, however, all of the fish died before the change could be effected.

Recoveries from injuries were noted several times. Two skipjack developed abrasions immediately posterior to their pectoral fins when first introduced. These abrasions covered areas about 3 cm in diameter, and may have been incurred by rubbing against the flange of the outlet pipe. On the fourth day after they were noticed, the abraded areas had healed.

Another injury noted initially as a circular "dark spot" about ½ cm in diameter on the left operculum of one of the fish developed

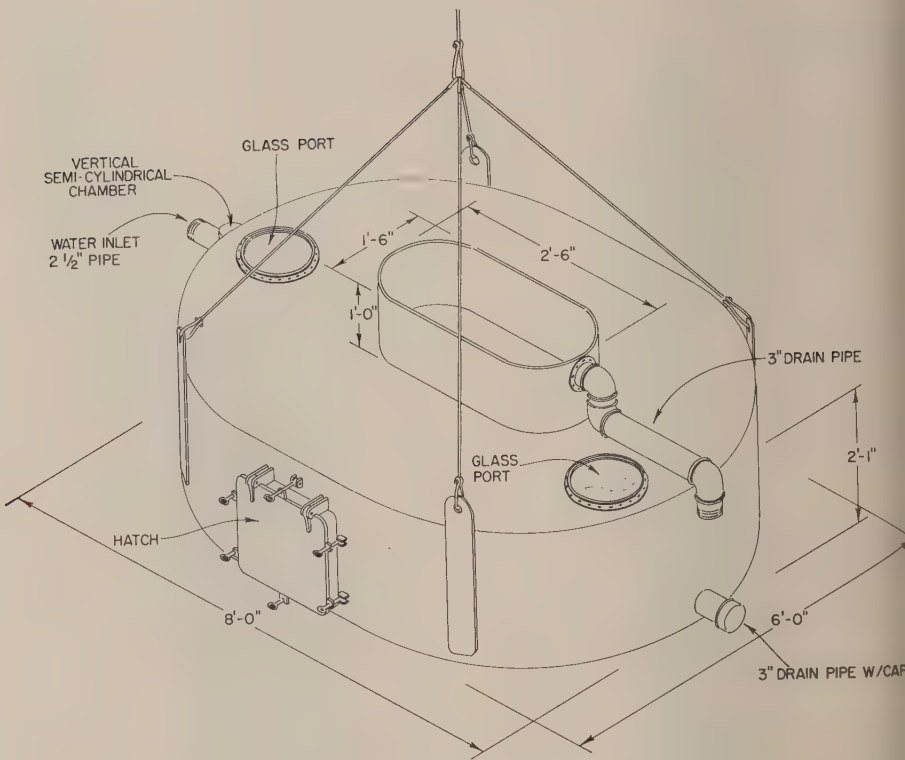

Fig. 3. Diagram of the portable fish tank used to transport skipjack tuna.

later into a perforation about 1½ cm in diameter. This wound healed in about 1½ months. No change in the feeding behavior of this fish was observed during this period.

One of the 2-pound skipjack was severely injured in its left eye by a hook during its capture. The eye eventually wasted away, leaving an empty eye socket. This fish swam with its body tilted to the right side, and although it often attempted to school with the others, it would usually be left behind. It survived for 15 days, during which it was never observed to feed. It became extremely emaciated. At the time of death, it had lost an estimated 10 ounces.

The skipjack, which lived the longest, suffered from "sunken eyes." Tester (1952b) noted the same malady in a captive yellowfin, *Neothunnus macropterus*. Although this condition appeared to hamper the skipjack's vision, it learned to feed by sighting food at a distance and rushing forward to take the food before it could sink. It often missed food that was thrown immediately in front of it. Four days before its death, it co pletely lost interest in food.

Summary

Euthynnus pelamis, a pelagic species tuna, was maintained in captivity for up 5½ months on a diet of shrimp, squid, a fish. Food consumption was 1.6 ounces p pound of skipjack per day when fed to sat tion once a day. When fed to satiation eve hour, food consumption was 3.2 ounces p pound of skipjack per day. Shrimp exosk etons passed through the digestive tract 1½ hours. Food was never taken from t bottom of the pool. When nearing satiati the fish would not take large pieces of fo or pieces of shrimp with the swimmer attached or pieces of squid with the tentac attached. Skipjack conditioned to water sla ping as a feeding signal reacted by swimmi towards the sound and developing dark v tical bands on their dorsolateral surfaces anticipation of food. The captive skipja were never observed to prey upon the sm fishes in the pool.

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ed in dead specimens are the series of
ht blue streaks on the scaleless portions
he dorsal and dorsolateral surfaces, the
te anterior edge of the first dorsal fin,
silvery tongue, and the dark vertical
ds on the dorsolateral surfaces, the latter
only in feeding skipjack.

he two size groups schooled together.
ool disruption occurred only during feed-
The fish swam with their mouths con-
tly agape. They were never observed to
swimming. No rheotaxis was demon-
ted.

rowth from 2 to 3 pounds occurred
in 3 months, but growth beyond 3
nds was not observed.

limination of manual handling of skip-
by the use of a portable fish tank per-
ted successful maintenance of this species
captivity. Recoveries from injuries were
erved. Causes of mortalities could not be
ermined.

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ENDOCRINOLOGIE. — *Cytologie hypophysaire et antigène sérique en relation avec la maturation sexuelle chez* Oncorhynchus species. Note (*) de Mlle **Madeleine Olivereau** et M. **George J. Ridgway**, présentée par M. Maurice Fontaine.

L'évolution des cellules gonadotropes décrite chez *Oncorhynchus species* est reliée à divers autres aspects biologiques de la maturation sexuelle, en particulier chez la femelle.

Divers aspects des recherches consacrées à la biologie du Saumon du Pacifique (*Oncorhynchus species*) sont liés aux méthodes permettant de distinguer les animaux au cours de la maturation sexuelle de ceux encore immatures. La taille des gonades ou le rapport gono-somatique ([1]) sont les critères les plus fréquemment utilisés ([2]), ([3]). Toutefois, la précision de ces méthodes reste discutable lorsqu'elles s'appliquent aux Poissons capturés au début de la période de maturation; l'étude histologique des gonades d'*Oncorhynchus*, méthode apportant seule un critère indiscutable, mais beaucoup plus longue, est actuellement poursuivie.

Mais de récentes recherches ont montré que le sérum du Saumon femelle au cours de la maturation sexuelle contient un complexe antigénique qui n'a pu jusqu'ici être mis en évidence dans le sérum du mâle ni dans celui de la femelle immature ([4]). La présence de cet antigène peut être décelée par immunodiffusion au début du développement ovarien. Cette réaction paraît ainsi constituer un critère de l'évolution sexuelle plus précoce que celui de la taille des gonades chez la femelle. Ce composé antigénique est également présent à une concentration élevée dans les œufs du Saumon et possède plusieurs caractères biochimiques (réaction tinctoriale avec Oil Red O et solubilité) similaires à ceux du vitellus ([5]).

L'électrophorèse sur papier met en évidence un composé probablement semblable dans le sérum de la femelle du Saumon coho (*Oncorhynchus kisutch*) ([6]) et de la Carpe ([7]) au cours de la maturation sexuelle. D'autres auteurs ont démontré la présence de composés voisins dans le sérum des femelles mûres ou traitées par les œstrogènes chez divers Vertébrés ovipares ([8]).

Afin d'étudier quelques-uns des mécanismes physiologiques contrôlant la maturation sexuelle et la synthèse de ce composé antigénique chez le Saumon du Pacifique, des *Oncorhynchus nerka* et *Oncorhynchus keta* sont capturés, soit en haute mer, immatures ou en cours de maturation (glandes prélevées par M. Robert Lander à bord du Navire de Recherches de l'U.S. Bureau of Commercial Fisheries), soit en eau douce, lors de la saison du frai. Les animaux sont tués rapidement, puis saignés; trente-deux hypophyses disséquées immédiatement sont fixées dans le liquide de Bouin Hollande additionné de chlorure mercurique. Elles sont coupées à une

épaisseur de 5 μ et traitées selon les techniques histochimiques déjà appliquées à l'hypophyse de l'Anguille ([8]), ([9]) permettant de distinguer parmi les cellules de l'adénohypophyse, les cellules thyréotropes δ et les éléments gonadotropes β et γ, bien que cette différenciation s'avère moins facile que chez les Vertébrés supérieurs. Nous envisagerons surtout ici l'évolution des cellules gonadotropes.

La structure générale de l'hypophyse d'*Oncorhynchus species* est similaire à celle de *Salmo salar* décrite précédemment ([10]). Les cellules gonadotropes sont presque exclusivement localisées dans la partie supérieure de l'adénohypophyse correspondant à la *pars anterior* des Mammifères. Chez les animaux immatures, elles sont déjà présentes, mais le cytoplasme est peu abondant et les réactions tinctoriales restent peu intenses. D'après leur aspect histologique, leur faible coloration et leur nombre restreint, elles ne semblent pas encore fonctionnelles. Cette image se retrouve chez tous les exemplaires dont le volume des gonades est inférieur à 20 ml, le volume étant plus facile à évaluer que le poids sur un bateau. Chez les Saumons dont le développement génital est plus avancé, ces cellules augmentent de nombre, de volume et leur coloration devient plus intense. Elles donnent une réaction positive avec l'aldéhyde-fuchsine, l'acide periodique-fuchsine de Schiff (P. A. S.), le bleu d'alizarine, le bleu alcian. L'association de l'orange G au P. A. S. ne permet pas de distinguer les deux types de cellules gonadotropes, mais avec le P. A. S., certaines volumineuses cellules possèdent de très fines granulations, d'autres plus petites renferment en outre de gros granules qui sont également colorables par le bleu alcian. La taille de ces granules paraît augmenter au cours de la maturation génitale.

Chez le Saumon lors du frai, ces deux catégories cellulaires sont plus faciles à distinguer, toutefois les gros granules sont progressivement déchargés, la cellule peut devenir hyperchromatique et le noyau pycnotique. Les autres éléments subissent une dégranulation et une vacuolisation partielle, puis totale, donnant des cellules vacuolaires presque vides ne contenant plus que quelques granulations colorables par l'orange G, semblables à celles retrouvées dans l'hypophyse du smolt de *Salmo salar* qui a frayé au cours de l'hiver précédent à l'état de parr. L'évolution de ces deux séries de cellules gonadotropes est similaire à celle décrite chez le Saumon de l'Atlantique (*Salmo salar*) et se retrouve chez le mâle et la femelle.

Il est toutefois intéressant de souligner que chez la femelle d'*Oncorhynchus*, la présence de cellules gonadotropes histochimiquement bien différenciées dans l'hypophyse s'observe seulement chez les animaux qui possèdent le complexe antigénique, lors du début de la maturation génitale réalisé en eau de mer. Des recherches en cours permettront de préciser la relation entre l'activité gonadotrope de l'hypophyse, la stimulation de l'ovaire et le mécanisme physiologique de la formation de cet antigène.

Une corrélation d'une autre nature nous est apparue, qui peut éclairer la signification fonctionnelle de certaines cellules hypophysaires : chez les individus capturés en mer lors d'une période de croissance particulièrement active, les cellules α, colorables par l'orange G (technique de Cleveland Wolfe) sont très volumineuses avec un appareil de Golgi qui semble bien développé. Leur aspect actif plaide en faveur de l'hypothèse d'une sécrétion d'hormone somatotrope par ces cellules, synthèse également postulée chez *Salmo salar* au cours de la smoltification ([11]) et chez les Vertébrés supérieurs.

(*) Séance du 15 janvier 1962.

([1]) Rapport gono-somatique = R. G. S. = poids des gonades × 100/poids du corps.

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Age and Growth of Spot in Lower Chesapeake Ba with Notes on Distribution and Abundance of Juveniles in the York River System[1]

Anthony L. Pacheco

ABSTRACT

Length-frequency distribution and scale samples of spot, *Leiostomus xanthurus*, were examined from 1955-58 pound-net catches in lower Chesapeake Bay. The scale method of age determination was validated for this sciaenid species. Few spot older than three years were found in the fishery to which they are generally available from April to October. Larger members of the young-of-the-year group may enter the fishery in July. A rapid rate of growth for the first two years is indicated with considerable overlap in sizes by age groups of older fish.

Exploratory trawl data for 1956-58 indicated seasonal distribution within the York River system and lower Bay, and annual variations in abundance, particularly that of young-of-the-year fish. A close apparent relation existed between annual recruitment to pound nets and trawl catch-per-unit-effort of young fish. Change of age composition in the pound-net catch and higher than average trawl catches of the 1956 year-class suggest this year-class was produced in dominant numbers.

Introduction

The spot, *Leiostomus xanthrus* Lacépède, is one of the most abundant food fishes of Chesapeake Bay and vicinity. Its chief commercial fishery is centered in the Virginia and North Carolina region. Commercial catches of spot in Virginia have varied from a low of 400,000 pounds in 1935 to a high of 8,000,000 pounds in 1949. Approximately 90 per cent of commercial catches are made by haul seines and pound nets. Gill and fyke nets take the remainder. Spot is also an important item in Virginia's salt-water sport fishery. Richards[2] estimated that in 1955 sportsmen caught one-eighth the weight of the commercial catch. Within Chesapeake Bay, spot are generally available to commercial and sport fisheries from April through October, the bulk being taken from August to October when spot are moving out of the Bay. During winter, this sciaenid fish is incidentally taken in the winter trawl fishery operating off the C Hatteras region (Pearson, 1932:18).

Features of the general biology and history of spot of the Chesapeake a have been concisely noted by Hildebr and Schroeder (1928:271–6). Subsequen Dawson (1958) published a notable rev of life history features.

Spawning apparently takes place offsh from Chesapeake Bay during late autu and winter. From the collection of p larvae (Hildebrand and Cable, 1930:4 off Beaufort, North Carolina it has b assumed that spot spawn from Novem to February. In Chesapeake Bay lar spot begin to appear in spring. During Ap spot 15–22 mm long have been taken plankton nets set in the York River n West Point (Pacheco, 1957:5). Spot ra ing from 22–85 mm have been comm in beach seine collections at Glouces Point during April and May. Some juve spot move far upriver, for Raney and Ma mann (1953:430) and Massmann (1954: report taking them in fresh and brack waters of the Pamunkey, Mattaponi Rappahannock rivers. These young main in waters of the Bay and tributa

[1] Contribution from the Virginia Institute of Marine Science, No. 109.

[2] Richards, Clarence E. A survey of saltwater sport fishing in Virginia, 1955–60, MS. Virginia Institute of Marine Science, The Virginia Fisheries Laboratory, Gloucester Point, Virginia.

eptember and October when they
to sea. The migratory pattern of
pot is similar to that of juveniles.
ish generally enter the Bay in late
nd May; however, seldom do they
te as far up the tributaries as juve-
heir seaward migration is coincident
onad enlargement. Some young-of-
r overwinter in deeper waters of
y (Hildebrand and Schroeder, *op.*
3); however, no older fish have been
d there. According to Dawson (*op.*
maturity is attained by late two-
rly three-year-old fish.

or subjects of this paper are elabora-
age and growth material (Pacheco,
determination of age composition
ound-net fishery, and presentation of
atory trawling results pertinent to life
of spot in the lower Chesapeake.

udy of age and catch composition of
aken in the pound-net fishery was
in 1955. In 1956 a series of monthly
surveys was initiated to obtain in-
tion on distribution and availability
nile fishes and to investigate the pos-
y of predicting trends for the com-
l fishery.

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Villiam J. Hargis, director, and the
rology research staff of the Virginia
ute of Marine Science (Virginia Fish-
Laboratory) offered valuable advice
rning the manuscript.

Methods

obtain the pattern of age composition,
pot were sampled weekly when avail-
throughout the fishing season, from
es of pound nets located in the lower
River area (Fig. 1). Fork lengths were
ured and scale samples taken from
randomly selected from the catch
g 1955. In following years, scale sam-
vere taken from every fifth fish of the
ish measured. All scales were taken
the shoulder region which were large
of symmetrical shape. Five unregen-
d scales from each fish cleaned in 0.1

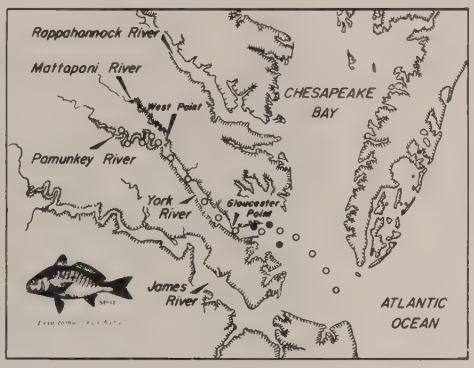

Fig. 1.—Portion of the lower Chesapeake Bay, Virginia, showing location of sampled pound-nets (solid circles) and stations of exploratory trawl survey (open circles). Locations mentioned in the text and a drawing of an adult spot are also shown.

N NaOH were mounted dry between glass slides and images observed by projection.

The exploratory trawl surveys consisted of 15-minute drags with a 30-foot semi-balloon trawl (one-inch mesh in wings and body, three-fourths-inch in cod end) at approximately 5-mile intervals. The monthly cruise course extended some 70 miles, from the mouth of the Bay, up the York River, into the Pamunkey River (Fig. 1). Further trawling details and summary of hydrographic data collected are presented by Massmann, et al. (1958).

Results

Estimation of Age From Scales

Examination of spot scales from New Jersey waters by Welsh and Breder (1923: 179) showed the presence of rings. These were so faint, however, age determination was difficult. Preliminary investigations by Townsend (1956) working with spot from Florida waters suggested that ages could be interpreted from scale marks. Sundararaj (1960) has validated ages of Louisiana spot by scale and otolith methods.

Spot scales were analyzed to determine characteristics usable as age criteria. The imbedded portion of a spot scale is sculptured with many closely spaced circuli (Fig. 2). Rings of densely packed circuli are usually associated with incomplete or broken circuli in the postero-lateral scale area.

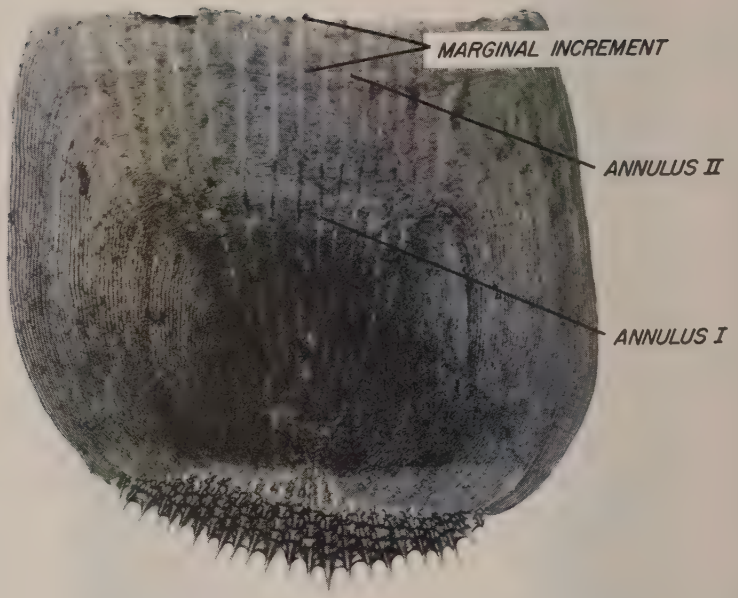

Fig. 2.—Photograph of a scale of the spot, *Leiostomus xanthurus*, showing the annuli.

Circuli are usually complete beyond these dense rings. Taylor (1916) described a similar feature for weakfish, *Cynoscion regalis*, as being a "narrow area parallel with the contour of the scale, in which the regularity of the circuli is interrupted, manifested as branches, breaks, or terminations." A variable number of radii are also characteristically present, and, as Taylor (*op. cit.*) found with weakfish scales, these radii may afford a supplementary aid in locating rings, since radii often originate from rings. If dense rings did not appear in all mounted scales examined from an individual fish, they were considered false marks. Criteria used by Sundararaj (1960:44) in evaluating marks are in agreement with those used for this study.

The annual nature of these dense rings of circuli can be demonstrated by showing that the marginal increment (distance from last ring to the margin of the scale) progressively increases in width throughout the year, from a minimum just after ring formation to a maximum just prior to formation of a new mark. Monthly samples of 1-ring spot from 1955 to 1958 (Fig. 3) show seasonal increase of marginal increment. Increase was apparent for all years, the rate of increase being somewhat gr in early summer. Annulus formatic essentially complete and marginal gr underway when fish become availab April (Fig. 3).

To show that annuli are formed d winter months when spot were not avai in Bay waters, a few samples were obt from the offshore trawl fishery from No ber 1955 to February 1956 (Fig. 4). Th quency distribution of marginal increr from 206 spot sampled from this ge shown in Table 1. It seems reasonab assume that annulus formation may during January. It is convenient to d January 1 as date of birth for each class, so biological and calendar yea incide.

Estimation of Age from Length Distribution

The monthly length-frequency dist tion of spot in the pound-net and exp tory trawl samples for the period 1 1958 is shown in Fig. 5. In reviewin distribution of lengths in the poun fishery a most interesting occurrence i appearance in July of a group of sm fish. As the season progressed, these

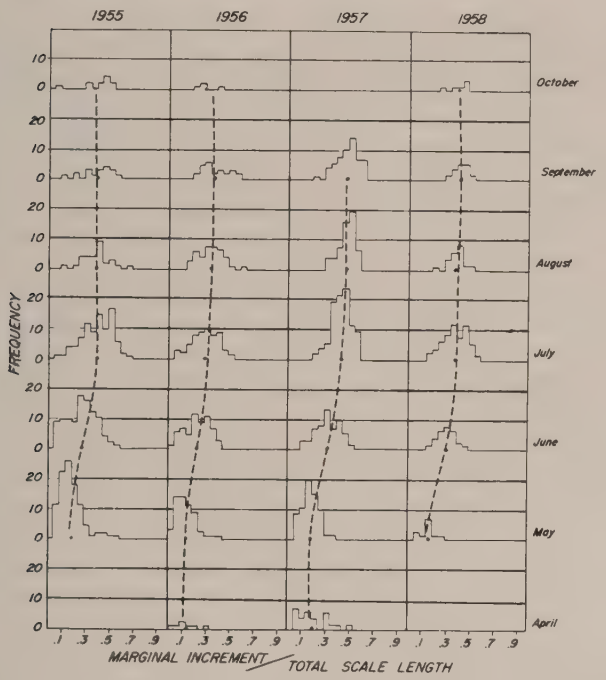

Fig. 3.—Monthly marginal growth distributions of one-ring scales of the spot, *Leiostomus xanthurus*, 1955–1958. Increment is expressed in per cent of total scale length; equency in numbers, except May and June 1955 where per cent frequency is shown. Dotted ne connects monthly means.

nded to dominate the catch in 1955 56. This new mode was absent from hery in 1957 and, in 1958 only of importance. From the trawl samples vious that only the larger members of ew mode are either available to or d by pound nets. The trawl net, s due to its lower selective limit, the mode of the new July group at ximately 100 mm, the interval to the al mode of impounded fish being 75 f a group of spot a year younger than 00 mm modal group were present, it be separated by an even wider in-; the existence of a younger modal is unlikely and indeed has not been ed. By using these premises it seems able to conclude that the July recruits ed to the current year-class. By ex-ation, this group may be said to have d sometime around January.

t fish caught during the first part of und-net season were in their second f life (Fig. 5). The position of this

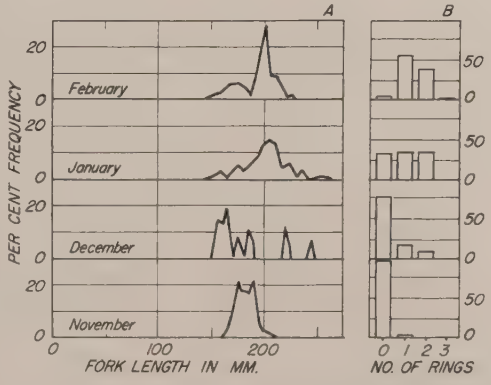

Fig. 4.—A. Monthly length-frequency distribution of spot, *Leiostomus xanthurus*, sampled from the winter trawl fishery 1955–1956. B. Age composition in corresponding months derived from scale reading.

right-hand mode (ca. 175 mm) progressed to the right at a slower rate, compared with the younger modal group. Fish older than two years may be included in the

TABLE 1.—Frequency distribution in arbitrary units of the growth zone of 0-ring and width of marginal increments of ranged scales in the spot, *Leiostomus xanthurus*. Samples from the winter trawl fishery, 1955–56.

Projected distance (mm)	November No. of annuli			December No. of annuli			January No. of annuli			February No. of annuli			
	0	1	2	0	1	2	0	1	2	0	1	2	3
0						1		1			2	2	
5								3	8		3	8	
10		1						4	6		13	7	1
15					1			4	1		2	2	
20					1				1		2		
25											1		
30		1						1					
35								2					
40								1			3		
45											1		
50													
55	2						3						
60	12			2			3						
65	30			2			3						
70	31			1			2						
75	12						1						
80	7						2						
85	2			1			1			1			
90				1						1			
95				2									
100													
Total	96	2		9	2	1	15	16	16	2	27	19	1

principal mode, but, if so, they cannot be distinguished on the basis of length alone. Gunter (1945) described a remarkably similar growth pattern for spot of Copano and Aransas bays, Texas, and the Gulf of Mexico.

Single monthly samples of spot from the winter trawl fishery (Fig. 4) indicated that the modal length was nearly the same as for the October 1955 Bay samples (Fig. 5). Throughout the winter, modal lengths were quite close, as may be expected when growth rate probably reaches a minimum. The winter mode seemed chiefly composed of one-year-old fish.

Age Composition of the Catch

The monthly percentage age-frequency distribution from 1955–1958 spot scales are illustrated in Fig. 6. It is evident that the 1955 and 1956 pound-net fisheries were supported mainly by two age groups of spot. Fish older than two years made up only a very small part of the total catch by bers. During these two years, the incr relative importance of the young-o year group accompanied by declining tive importance of the one-year-olds parent throughout the season. During the 1956 year-class dominated the concurrently, no young-of-the-year fis obtained in commercial samples. In three-year-old fish were in much g relative abundance than in earlier These same interpretations could be from length data; however, the scale m contributes obvious refinements in d ing the age groups constituting the right-hand mode of length distributi

From observations of the catches, is reason to believe the 1956 year-clas produced in dominant numbers. The ponderance of this group of fish in years supports this observation.

The rapid percentage decrease in c bution of older fish to the stock seems a characteristic of the spot population. the first year, a total mortality rat clusive of the 1956 year-class) of ap mately 80 per cent is suggested fro composition analysis.

The Scrap Fishery

The colorful history and operati pound nets in Virginia has been summ by Reid (1955). With present mesh s portion of the catch is unmarketable. smaller sizes are culled into scr heterogeneous collection of undersiz undesirable fish sold to reduction pla as crab bait (McHugh, 1960). The s spot taken in the pound-net fishery r from about 100 to 250 mm (Fig. 5). erally, however, only spot over 17 are marketed. Since scrap entries are n cluded in catch records, estimates of w and numbers of spot in scrap were lated by extrapolation from lengt quency data, the length-weight relati (Pacheco, 1957) and logbook recor the commercial catch. From two ye fishermen's logs of catch (1956, 195 estimate of this portion of the fisher computed (Table 2). From this con tion, it appears that approximately

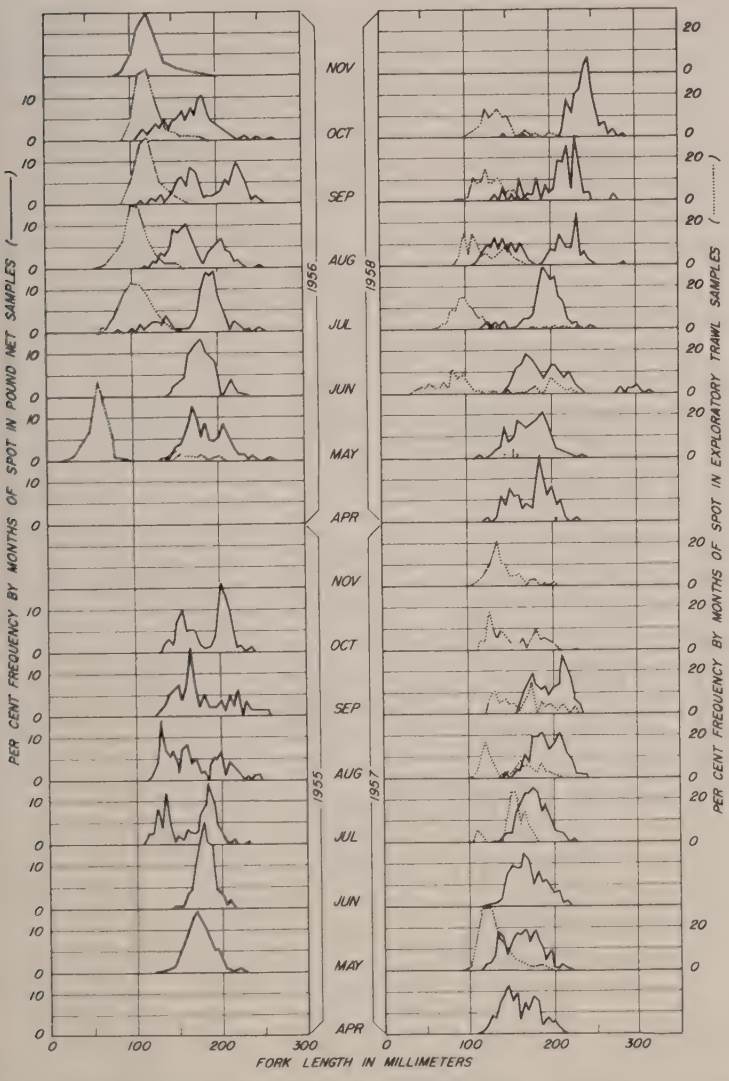

Fig. 5.—Length-frequency distribution of spot, *Leiostomus xanthurus*, in the pound-net atch, 1955–1958, grouped by months. Length-frequency distributions of the exploratory rawl survey for same periods represented by dotted lines.

of the 1956 year-class by numbers entered the fishery were considered in 1956 and 1957. Since the 1956 year- was large this estimate may approach ximum.

:PLORATORY TRAWL CATCH OF SPOT

]mination of the length-frequency dis- ion of spot taken by the exploratory trawl survey gear (Fig. 5) indicates that the fish generally sampled were the smaller members of the youngest age group exploited by the pound-net fishery, particularly evident in 1956 and 1958 collections. During 1957 fish of the older modal group were also taken by trawl. This was verified by scale reading.

A size gradient was generally evident

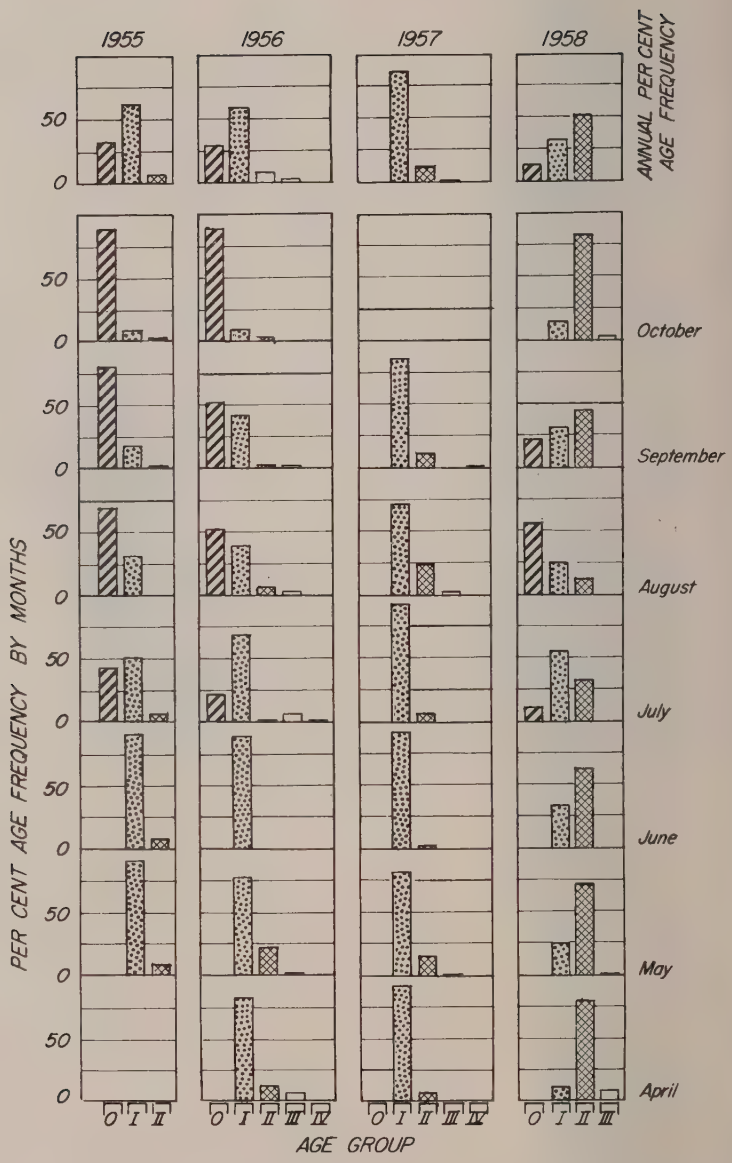

Fig. 6.—Percentage age-frequency composition of the pound-net catch of spot, *Leiostomus xanthurus*, 1955–1958, showing monthly and yearly changes in age composition determined from scale reading. Ages coded as follows: young-of-the-year, barred; one-ring, stippled; two-ring, cross-hatched.

within each age group of trawled fish in which the smaller members were found in the upriver areas. Only young-of-the-year spot were taken in the Pamunkey River.

Catches from 1956 to 1958 are grouped by stations into juvenile and older categories and are shown in Table 3. Seasonal n of catch-per-unit-effort are shown in F From a comparison of the catches ma different years, it is obvious that the year-class was exceptionally large. Th fect of this large group is also evident

ly greater numbers of older spot
1957 and 1958. The 1957 year-class
ailable only in comparatively sparse
s. In 1958 the relative number of
s increased, however not on the
f the 1956 group. Since a year-class
nile spot may not be fully recruited
commercial fishery their first year,
accurate measure of their relative
nce may be obtained from explora-
wl data. The mean monthly catch of

.—Estimated numbers and weight of spot,
omus xanthurus, of various ages repre-
l in log-book returns, 1956–57.

Marketable fish							
Estimated Pounds				Estimated Numbers			
Age group							
0	1	2	3	0	1	2	3
—	13	5	1	—	41	13	2
—	33	8	2	—	149	20	3
—	6,220	469	999	—	20,063	1,020	2,040
2,065	11,797	2,319	745	9,833	34,698	5,521	1,773
4,841	19,654	3,791	846	19,362	40,109	4,860	1,626
20,145	6,292	2,424	—	77,480	11,871	2,956	—
27,051	44,009	9,016	2,593	106,675	106,931	14,390	5,444
	67	88	—	—	280	303	—
—	5,662	608	—	—	23,591	2,433	—
—	41,984	5,136	—	—	174,932	16,568	—
—	35,381	18,741	2,612	—	131,042	53,546	5,225
—	48,767	19,085	—	—	207,360	42,412	—
—	131,861	43,658	2,612	—	537,205	115,262	5,225

Scrap fish							
—	2	—	—	—	13	—	—
	8				51		
62	504			771	2,799		—
5,588	—	—	—	39,914	—	—	—
1,159				29,705			—
5,730			—	49,928	—	—	—
—	—	—	—	—	—	—	—
15,539	514	—	—	120,318	2,863	—	—
	177	9	—	—	1,609	56	—
	6,939				49,565	—	—
	2,166		—	—	14,443	—	—
	4,273				26,704	—	—
—	11,743			—	69,075	—	—
—	25,298	9	—	—	161,396	56	—

TABLE 3.—Numbers of young-of-the-year and older spot, *Leiostomus xanthurus*, trawled per hour in Chesapeake Bay, York and Pamunkey rivers from April 1956 to December 1958.

Date	Young-of-the-year spot					Older spot				
	Chesapeake Bay	Lower York R.	Upper York R.	Pamunkey R.	Mean	Chesapeake Bay	Lower York R.	Upper York R.	Pamunkey R.	Mean
1956										
Apr	0	0	0	0	0	0	0	0	0	0
May	2	5	474	13	124	0	16	20	0	9
Jun	*	*	*	*	—	—	—	—	—	—
Jul	422	240	135	1	200	0	0	0	0	0
Aug	210	229	472	6	229	0	1	3	0	1
Sep	364	516	313	3	299	0	0	0	0	0
Oct	169	130	40	10	87	0	0	0	0	0
Nov	69	770	233	10	271	0	1	0	0	1
Dec	2468	28	8	0	626	0	0	0	0	0
1957										
Jan	0	0	0	**	0	6	1	7	**	4
Feb	0	0	0	0	0	0	0	0	0	0
Mar	0	0	0	0	0	1	0	0	0	0
Apr	*	*	*	*	—	—	—	—	—	—
May	*	12	31	4	16	*	34	146	0	45
Jun	*	*	*	*	—					
Jul	3	*	*	*	—	38	*	*	*	38
Aug	6	91	3	4	26	13	46	24	0	21
Sep	13	19	7	0	10	4	17	21	0	10
Oct	3	17	40	2	16	12	6	13	0	8
Nov	74	2	24	0	25	3	0	0	0	1
Dec	10	17	1	0	7	0	0	0	0	0
1958										
Jan	0	0	0	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	0	0	0
Mar	0	0	0	0	0	0	0	0	0	0
Apr	0	0	0	0	0	1	0	0	0	1
May	0	0	0	0	0	1	1	2	0	1
Jun	0	17	718	6	185	1	8	50	0	15
Jul	1	153	655	76	221	0	9	5	0	4
Aug	87	57	513	42	175	0	0	0	0	0
Sep	0	3	104	20	32	0	1	4	0	1
Oct	9	10	52	0	18	0	2	3	0	1
Nov	29	121	50	8	52	0	0	0	0	0
Dec	0	1	0	0	1	0	0	0	0	0

* No survey.
** River frozen.

young-of-the-year spot in exploratory trawls from April to December follows closely the annual percentage of young-of-the-year in the pound-net fishery determined by scale analysis (Fig. 8).

RATE OF GROWTH

Mean lengths and standard deviations of the various ages of spot taken in pound-net samples are grouped by months from the 1955–1958 fisheries in Table 4. Growth rate

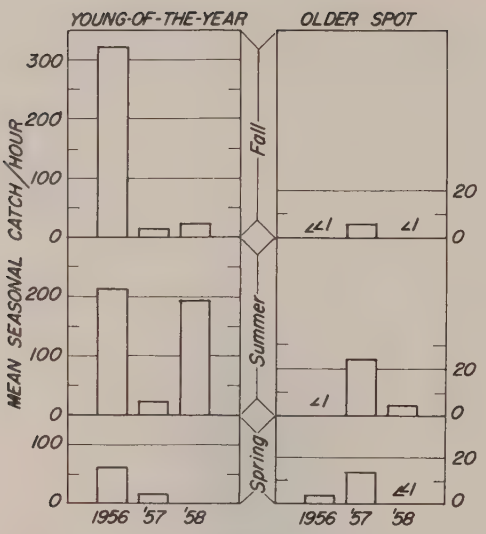

Fig. 7.—Mean seasonal catch-per-unit-effort of spot, *Leiostomus xanthurus*, caught in exploratory trawl surveys, 1956–1958.

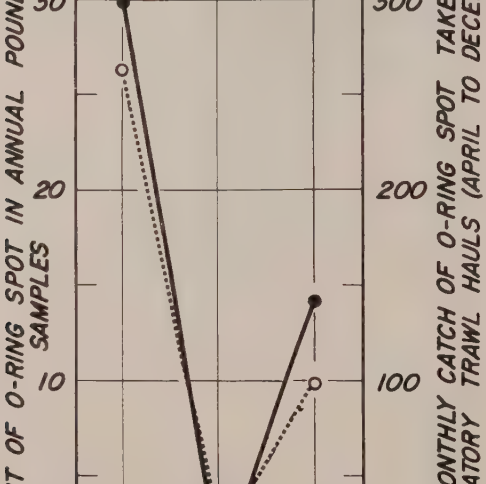
PER CENT OF O-RING SPOT IN ANNUAL POUND-NET SAMPLES
MEAN MONTHLY CATCH OF O-RING SPOT TAKEN IN EXPLORATORY TRAWL HAULS (APRIL TO DECEMBER)
1956
1957
1958

Fig. 8.—Relationship of relative abundance of young-of-the-year spot, *Leiostomus xanthurus*, in the pound-net catch (solid line) to catch-per-unit-effort of the same age group in exploratory trawl hauls (dotted line), from sampling summary 1956–1958.

TABLE 4.—Mean length (mm), standard d tion, and sample size of various ages of *Leiostomus xanthurus*, sampled from pound 1955–58, grouped by months.

Date	Age in years	1955			1956			1957			1
		$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$
April	I	—	—	—	176.8	27.0	14	157.4	20.3	56	153.3
	II	—	—	—	230.0	21.2	2	188.7	14.3	4	185.0
	III	—	—	—	—	—	—	—	—	—	177.5
May	I	171.6	13.8	271	187.5	18.6	78	152.8	19.9	66	163.0
	II	191.7	20.5	29	215.5	24.9	21	189.2	17.4	3	186.2
	III	-	—	—	—	—	—	175.0		1	195.0
June	I	179.8	10.7	182	177.5	10.8	61	167.8	15.3	59	175.9
	II	189.1	11.3	16	207.5	19.7	6	187.5	3.6	2	204.6
	III	—	—	—	225.0	—	1	—	—	—	200.0
July	0	135.2	12.8	79	134.6	15.0	23	—	—	-	143.5
	I	184.0	10.1	91	196.0	12.1	77	175.5	15.2	94	191.0
	II	196.0	13.7	10	217.5	45.0	2	198.3	9.9	6	209.7
	III	-	—	—	225.7	14.0	7	—	-		215.0
	IV	—	—	—	237.5	10.6	2	—	—	—	—
Aug.	0	147.1	16.8	68	162.8	13.3	52	—	—	-	146.7
	I	205.0	15.6	30	204.7	10.3	39	187.8	17.2	58	208.0
	II	—	—	—	216.7	14.4	6	205.2	15.8	20	224.5
	III		-	—	226.7	20.2	3	227.5	10.6	2	235.0
Sept.	0	167.4	22.2	64	170.0	18.1	32	—	—	—	165.4
	I	224.0	18.9	15	225.8	13.1	25	187.4	17.9	47	219.1
	II	230.0	—	1	235.0	10.0	2	211.4	27.0	7	225.0
	III	—	—	—	230.0	—	1	275.0	—	1	—
Oct.	0	181.2	24.9	89	177.1	19.4	43	—	—	—	—
	I	211.1	13.2	9	230.0	10.8	4	—	—	—	223.3
	II	215.0	—	1	—	—	—	—	—	—	244.5
	III	--	—	—	—	—	—	—	—	—	275.0

estimates for the 0-age group may appr a maximum, since selectivity by pound introduces some bias against smaller Young-of-the-year spot taken in Oct exploratory trawl hauls had a modal le of approximately 120 mm (Fig. 5), 40 smaller than the same age spot san from pound nets at this time. Henc evaluating and comparing estimate growth between and within areas, a sideration of sampling gear type, size, and location is important for p interpretation.

The mean monthly sizes of one-yea fish in 1957 pound-net samples were erally significantly less than the c sponding monthly means of that age g in the other years' samples. The phenom of depressed growth appears to be a f common feature of abundant age g (MacGregor, 1959).

Discussion and Conclusions

It has been demonstrated that only annulus is formed on spot scales each

nuli being produced in the period nuary to February. This is in close nt with results obtained by Sun- (1960:45), who indicated time of formation to be February and early in Louisiana waters. Scale studies at the fishery in the lower York s generally supported by two age the O- and one-year-old fish. Fish an two years commonly make up small portion of the total catch. An trend throughout the season is the ng relative occurrence of the O-age ish. Two major modal groups typi- ppear in the frequency distribution ths. The mode of smaller fish gen- appears in July and represents fish first year of life. The larger size possibly includes two or more age The close agreement in results de- rom comparison of length-frequency tions and scale analysis confirms onclusions.

pattern of predominance of young the fall could be considered broken October 1955 length-frequency dis- on. This bimodal distribution, how- as shown from scale readings to be up almost entirely of young-of-the- sh. Only two samples were obtained ober, and each modal group repre- ne sample, the smaller mode repre- the last collection. This bimodality eflect a differential movement with to size. Exploratory trawl surveys hown that spot of a given age group stributed according to size in the the smaller individuals occurring am. This differential distribution typical of many estuarine forms, as y (1955) has suggested for men- *Brevoortia tyrannus*, and Haven has shown for croakers, *Micropogon tus*. With the onset of fall migration, October samples contain the larger f an age group, since the smaller rs located upriver and upbay prob- ass into the area of capture after the members of the group have departed. ious growth features of Chesapeake re the relatively rapid growth of the -of-the-year group and the spread and p in sizes of older fish (Table 4). At the end of their first year, spot taken by pound nets average approximately 170 mm, and at the end of their second year they approximate 220 mm. Fish older than two years were larger, on the average, than one-year-old fish, but could not be separated from them on the basis of length alone. The lengths and age composition of spot sampled from the winter trawl fishery suggest that little or no growth takes place in winter; however, more adequate sampling of this fishery would be desirable. The winter trawl data were valuable in illustrating the time of annulus formation.

Exploratory trawl hauls showed the seasonal distribution of juvenile spot in the York River system. Compared to pound-net samples, experimental hauls consistently caught smaller individuals of each age group, probably due to differential net selectivity. A close apparent relationship appears to exist between annual exploratory trawl catch level of young-of-the-year spot and their coincident abundance in the pound-net fishery. From this it follows that survey catches alone may be of considerable value in estimating yearly abundance of young and in predicting catches and trends of the fishery at least a year in advance.

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Movements of Spot, *Leiostomus xanthurus*, in the Lower Chesapeake Bay[1]

ABSTRACT

A tagging study of spot was conducted in two er Chesapeake estuaries. Limited summer vement of spot was exhibited suggesting the sibility of assessing fishery exploitation by in- idual river systems. Two returns from the win- trawl fishery operating in the Hatteras area re indicative of an overwintering area.

Although the spot, *Leiostomus xanthurus* Lacépède, is a relatively important commercial and inshore sport fish, little has been documented on its movements in Chesapeake waters. Statements regarding its seasonal movements (Hildebrand and Schroeder 1928:271–6; Pacheco 1962:18–9) are based on inferences drawn from observations of

[1] Contribution No. 124, Virginia Institute of Marine Science, Gloucester Point, Virginia.

BLE 1.—Release and recapture summary of spot, *Leiostomus xanthurus*, tagged in the York and Rappahannock Rivers, 1957. Data are grouped by tag types.

Releases			Returns			
Date	No. Petersen	No. Streamer	Area	Days out	Miles from release	Gear[1]
			York River			
ril		49	Yorktown, York R.	41	5	S
			Clay Bank, York R.	4	3	SG
			Poquoson R.	55	5	HS
			Ches. Bay, off Gwynn, Va.	76	19	S
			Poquoson R.	12	5	HS
			Pages Rock, York R.	(in 1958)	2	SG
	55		Nomini Bay, Potomac R.	68	74	HS
			Clay Bank, York R.	10	14	SG
			Pages Rock, York R.	—	1	F
			Muddy Bight, York R.	55	2	HS
			Ches. Bay, Horn Harbor	89	10	HS
			Severn R.	39	7	HS
			Back R.	47	3	AG
			Severn R.	39	7	HS
			Guinea Marsh, York R.	(in 1958)	2	HS
ly–Sept.		164	Sandy Point, York R.	11	0.5	P
			Perrin, York R.	1	0.5	P
			Perrin, York R.	1	0.5	P
			Sandy Point, York R.	2	1.5	P
	173		Sandy Point, York R.	11	0.5	P
			Perrin, York R.	1	0.5	P
			Perrin, York R.	1	0.5	P
			West Point, York R.	29	17	S
			Naval Mine Pier, York R.	13	3	AG
			Green Point, York R.	7	11	AG
			Middle Ground, James R.	68	22	AG
			Back R.	74	19	AG
			Rappahannock River			
pt.		28				
	27		4 mi. W. Diamond Shoal	133	178	T
			10 mi. W. Diamond Shoal	155	200	T

[1] Gear coded as follows: AG (anchor gill net), F (fyke), HS (haul seine), P (pound net), SG (stake l net), S (sport), and T (trawl).

catch in various localities. Commercial sized spot are absent from Bay waters in the winter; however, occasional catches are reportedly made in the winter by trawlers operating in the ocean, indicating a migration to these waters at this season. Within the Bay, commercial catches of spot begin in the spring, during April or May, and continue until September and October when fish again leave the Bay. The bulk of the commercial catch is made during the fall migration.

To date, the only reference to tagging of spot is that cited by Pearson (1932:6) and reiterated by Nesbitt (1954:76) as "A single record indicates the movement of a tagged spot from Delaware Bay to the vicinity of Ocracoke Inlet, N.C., between October, 1930, and December, 1930."

To obtain a measure of the extent of summer movement and possible information on the overwintering area, approximately 500 spot were tagged during the summer of 1957. Of these, 441 were released in the York River, and 55 released in the Rappahannock River in late summer. In both rivers releases were made from the mouth to 10 miles upriver. Fish were collected by trawl, operated from the research vessel *Pathfinder*, and maintained in a deck tank of circulating water until measured, tagged and released. They ranged in fork length from 150 to 255 mm, with a modal size of 170 mm. Petersen disc and monofilament nylon streamer tags were used in about equal numbers. Tags were attached through dorso-lateral musculature under the basals of the spiny dorsal fin. From regular contact with fishermen and in response to press releases, 29 tags were recovered.

Summary releases and recapture data were presented in Table 1. From the April tagging most returns were from the York River system. All river returns were from within 14 miles of the tagging site. Returns from Horn Harbor and Gwynns Island in the Chesapeake and from Nomini Bay, Potomac River, suggest some limited early summer northern movement.

Of fish released in July and August, all returns before November were made in the York River. November returns from the mouth of Back River and the James suggest an out-Bay, southerly movement. Of interest are returns from two fish recaptured during the 1958 season, both retur from the York River.

From the limited Rappahannock River tag in early September, no returns were taken wi the Bay. Of particular interest, however, was capture of two spot, released near Urbanna, trawlers operating inshore of Diamond Shoal li ship (Cape Hatteras, N.C.) in January and Fe ary, 1958. In many respects movements of s appear comparable to those described for croaker, *Micropogon undulatus*, by Haven (19 25–6).

During 1957, 10.2 and 13.6 per cent respectiv of streamer and Petersen tags were returned f the April tagging in the York River. From Jul September tagging, 2.4 per cent of streamer 4.8 per cent of Petersen tags were returned f York River releases.

The restricted nature of this study precludes estimate of fish removed by various segments the fishery. Further tagging studies on a much panded basis are warranted to estimate explo tion by the fishery. The apparent stability of r populations during summer may expedite ass ment of the resource in individual areas.

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Cottid Predation upon Salmon Fry in a Washington Stream

In view of human exploitation and the environmental hazards encountered by pacific mon (*Oncorhynchus*), every effort must be de to aid and promote the survival and wth of the juveniles of this important fish- resource. It is during the freshwater rsery stage that 90 percent of the losses of mon occur. It is generally known that ier species of freshwater fishes adversely ect the survival of young salmon at this ge. The freshwater sculpins of the genus ttus are usually abundant in salmon spawn- and nursery streams. The following dis- ssion concerns predation by *Cottus rhotheus* d *C. perplexus* on coho salmon fry, *O. utch.*

MATERIALS AND METHODS

Sculpin collections were taken from Newau- m Creek, forty miles southeast of Seattle, tween April 2 and May 14, 1959. Three col- tions were made in tributaries having flows less than 8 cubic feet per second, and four mples were taken from the main creek, hich increased in flow downstream from 20 80 cubic feet per second. The April 2 mple was taken at a time of increased flow llowing rains, and the entire stream in the udy area had considerable submerged cover. Fish were collected with a square-wave, direct-current, electrofishing unit. Collections were placed in formalin and processed in the laboratory. Fry remains in the stomachs were identified with the aid of a dissecting scope when necessary.

Fishes collected were the torrent sculpin, *Cottus rhotheus*, the reticulate sculpin, *C. perplexus*, and the coho salmon. The stomachs of all cottids over 40 millimeters in length were examined. The smallest coho predator found in Newaukum Creek was 73 millimeters in length. Hunter (1959) found predation on pink salmon, *Oncorhynchus gorbuscha*, and chum salmon, *O. keta*, fry to begin in the 51–60 millimeter length group, but appreciable consumption by the prickly sculpin, *Cottus asper*, and coast-range sculpin, *C. aleuticus*, occurred only in length groups above 60 millimeters. Sheridan and Meehan[1] found predation on pink salmon fry by *C. aleuticus* of 27 millimeters. For Newaukum Creek, predation on coho fry by cottids less than 64 millimeters long was considered inconsequential. Only individuals over 64 millimeters will be termed predatory-sized for this study.

RESULTS

Insects comprised the bulk of the stomach contents, and salmon fry were incidental in both cottid species (Table 1). None of the cottids examined had eaten more than one fry, except that one 107-millimeter *Cottus rhotheus* had taken two. About 5 percent of the *C. rhotheus* and 10 percent of the *C. perplexus* had empty stomachs. Empty stomachs appeared randomly distributed in all collections and sizes of cottids.

Predation was not as intense in the main creek as in the tributaries except at the time of the April 2 sample. The cottid samples from the main creek showed a substantial percentage of predation except on April 16. The incidence of salmon predators among predatory-sized cottids from all samples of *Cottus rhotheus* was 9.2 percent; of *C. perplexus*, 3.1 percent; and combined, 7.9 percent.

[1] Sheridan, William L., and William R. Meehan (1962) Rehabilitation of Big Kitoi outlet stream, Afognak Island, Alaska. Alaska Department of Fish and Game, Division of Biological Research (Juneau), Information Leaflet No. 11, April 3, 1962. 13 pp. (Processed).

TABLE 1.—*Incidence of salmon fry predation by predatory-sized* Cottus *in Newaukum Creek in 1959*

Sampling site	Collection date	Species	Number examined	Number of cottids containing fry	Frequency of predation (percent)
Upper main creek	April 2	*C. rhotheus*	16	5	31.3
		C. perplexus	2	1	50.0
Tributary	April 7	*C. rhotheus*	26	3	11.5
		C. perplexus	1	0	—
Main Creek	April 9	*C. rhotheus*	30	2	6.7
		C. perplexus	5	0	—
Main Creek	April 14	*C. rhotheus*	42	2	4.8
		C. perplexus	2	0	—
Main Creek	April 16	*C. rhotheus*	106	2	1.9
		C. perplexus	10	1	10.0
Tributary	April 16	*C. rhotheus*	25	5	20.0
		C. perplexus	18	0	—
Tributary	May 14	*C. rhotheus*	69	9	13.0
		C. perplexus	26	0	—

Growth of coho salmon fry during the study was from a mean length of 35 to 40 millimeters. The length range of fry sampled was 29 to 56 millimeters; and of fry consumed, 32 to 45 millimeters. The cottid lengths shown in Figure 1 were used to test the hypothesis that *Cottus rhotheus* which had consumed fry were equally represented in all length groups of predatory-sized cottids. A t value of 0.98 (1.97 = rejection) indicated acceptance of the hypothesis.

DISCUSSION

Cottids probably did not feed specifically on coho salmon fry in Newaukum Creek, but took whatever foods were most available. Pritchard (1936), Ricker (1941), and Salo[2] found that in unnatural situations cottids will gorge on salmon fry if such an opportunity is presented. Hunter (1959) has shown that under natural conditions larger cottids will average five fry per stomach. In Newaukum Creek, however, all but one predatory cottid had consumed but a single fry; the exception had taken two. Nearly all of the Newaukum Creek predatory cottids had additional food items in their stomachs.

It is suggested that the higher frequencies of cottid predation in the Newaukum Creek study areas are a function of coho fry density surpassing suitable cover. Predation frequencies were consistently higher in tributaries than in the main creek. Fry populations a peared dense throughout the tributaries, b only moderate in the main creek, except f abundances in areas of cover. The fry in t main creek were usually along the banks or the areas of cover. The highest predation fr quency was in the upper main creek at a tir of increased discharge from rains. Apparent swift waters had decreased suitable fry hal tat to eddies along the banks, concentrati the fry there.

Hikita and Nagasawa (1960) indicated t density-dependent nature of *Cottus nozaw* predation upon chum salmon (*O. keta*) in te flumes. The rate of predation on 200 chu salmon fry by five sculpins gradually d creased to zero by the time the prey were r duced to 70. At this point sculpins died starvation.

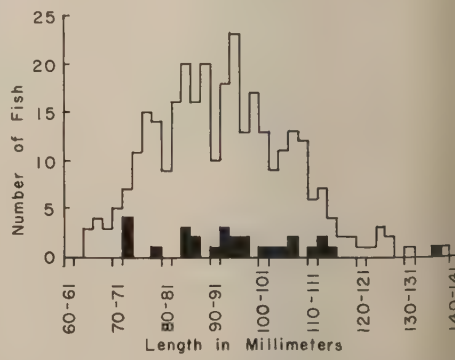

FIGURE 1.—Length–frequency of Newaukum Cre *Cottus rhotheus*. Salmon fry predators are shaded

[2] Salo, E. O. (1952) Chum and pink salmon. Washington State Dept. Fish., Minter Creek Biol. Station, Prog. Rept., Feb. 1952 to April 1952, 4 pp. (Mimeo.).

he possibility of a density-dependent factor small stream with resident prey, such as , suggests a compensatory factor in stabi- g fry population levels. When fry num- are high, predation will reduce their ulation to a point of stability. If the fry initially sparse, predation will be minimal. would compensate for years of poor fry duction resulting from reduced adult pement or adverse incubating conditions ncreasing the survival rates of fry.

hree different cottid-salmon situations may compared. Ricker (1941) found that bot- dwelling *C. asper* could not be considered edator upon natural populations of pelagic keye (*O. nerka*) young in Cultus Lake. s is almost predictable because of habitat erences of the two species. Hunter's 59) work on Hooknose Creek and the nor's findings from Newaukum Creek show feeding patterns assumed by cottids in ams. *Cottus aleuticus* and *C. asper* in oknose Creek preyed almost exclusively n pink and chum salmon fry (apparently lense concentrations and readily available) ch were moving downstream at night and king daytime protection in the gravel. se cottids took constant numbers of fry to ir capacity throughout the main migration. ring the Newaukum Creek study, *Cottus theus* and *Cottus perplexus* fed mainly on insect life and only incidentally upon coho fry, which at this stage could be regarded as nonmigratory. The fry abundances in Newaukum Creek were apparently too low for rates of predation as high as Hunter found.

Cottus perplexus does not appear to be as predaceous upon salmon fry as *C. rhotheus*. Since the overall size and mouth capacity of these two sculpins are comparable, other factors such as specific feeding habits and habitat preferences may be of significance.

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:POSURE OF SEVERAL DEVELOP-
:TAL STAGES OF THE SEA LAM-
:Y. *PETROMYZON MARINUS*, TO
:CTIVE LARVICIDES. ***Abstract.***—**Sea
prey at several different developmental
s were exposed to chemicals that are
tively toxic to lamprey larvae. The
er embryonic stages (unfertilized ovum
ugh prehatching, Stages 0 through 13)
exposed to test chemicals for a period
4 hours. Development proceeded beyond
stage at treatment for 1 to 3 additional
s before death ensued. In all cases,
rion of death was disintegration of the
ryo. Prolarval stages (larva still bearing
. Stages 14 through 17) exposed to larvi-
s for the entire experiment withstood
tment until they entered Stage 18 (larva),
reupon death came rather suddenly.
e 18 larvae died within hours after ex-
ure. An inhibition of the hematopoietic
m seemed to occur in those prolarvae
ted prior to Stage 15 (pigmentation).
am treatment with larvicides for the
rol of sea lampreys apparently should
ccomplished 40 days after spawning has
ed to insure destruction of larvae in the
e highly susceptible stages.**

ontrol of the sea lamprey, *Petromyzon*
inus Linnaeus, in the Great Lakes has
n centered around certain selectively
c chemicals. The larval stages in the
prey life cycle were the object of prac-
lly the entire testing program conducted
the Hammond Bay Fishery Laboratory.
e present study was undertaken to deter-
ne whether some of the chemicals desig-
ed as specific larvicides by Applegate,
l. (1957. *U. S. Fish & Wildl. Serv. Spec.*
Rept. Fish. (207):1–157) would have
effect upon the developing embryos (un-
ilized ovum through prehatching, Stages
rough 13), prolarvae (larva still bearing
s, Stages 14 through 17), and Stage 18
ae (all major body systems developed
ept genital). Applegate, *et al.* (1958.
nce 127:336) already had determined
approximately 6 chemicals out of thou-
ds tested had a specific toxicity to sea
prey larvae in the 2- to 5-year classes.

n the summer of 1956, sea lamprey em-
os in various stages of development
avis, 1961. *U. S. Fish & Wildl. Serv. Fish.*
l. 61(182):111–43), ranging from Stage 8 (blastula) through Stage 18 (larva of the year), were subjected to the several larvicides at concentrations of 10 ppm. Embryos, prolarvae, or larvae were placed into beakers containing about 800 ml of solution of individual chemicals tested. Each beaker was immersed below the solution-level in a constant-temperature trough, preset at 65°F (18.4°C), and equipped with an air bubbler. Specimens were exposed to the chemical solution for the duration of the experiment except as noted in Table 1. Those specimens exposed for shorter time intervals were washed several times and maintained in beakers provided with fresh water. Observations were made at varying intervals depending upon the stage of development at initiation of the test. They were hourly until death during experiments on Stage 18 larvae; the experiments on prolarvae and embryos were observed several times during the first day and daily thereafter.

Criteria of death in the earlier embryonic stages were similar in all tests. These embryos at first seemed to increase in size and within 24 hours disintegrated within the intact chorion. Prior to death both the prolarvae and larvae developed the following symptoms: immediate and constant twitching of head and trunk; irregular heart beat; distention of pericardial cavity and accumulation of blood within it; spasmodic respiratory rate; distention of gall bladder, when present. An untreated control batch was maintained at 65°F (18.4°C) throughout all chemical tests. This batch provided specimens for the tests.

The results from this series of experiments can be interpreted best from examination of the records of Table 1. The table was arranged to facilitate comparisons of results from the treatment of prolarvae and larval Stage 18 and results from treatment of earlier stages. All Stage 17 prolarvae as well as Stage 18 larvae were exposed to the chemical for the duration of each experiment. The prolarvae withstood chemical treatment for days until they reached Stage 18 (larvae) after which death was sudden. Except for those specimens treated with chemical VII, 4-styrylpyridine, all chemically treated Stage 18 larvae were killed within a few hours. Exposure of all early stages to chemicals for 24 hours caused death in all embryos. Before

TABLE 1. RESULTS OF EXPOSURE OF SEVERAL DEVELOPMENT STAGES OF SEA LAMPREY, *Petromyzon marinus*, TO LARVICIDES AT A CONCENTRATION OF 10 PPM

[The stages of development are from Piavis (1961)]

Chemical[1]	Developmental Stage at Start of Test	Duration of Exposure[2]	Term of Experiment	Developmental Stage at End of Test	Percentage Dead	Number of Specimens
I	17	Entire	18 d[2]	18	100	20
I	17	Entire	14 d	18	100	25
I	18	Entire	2–4 h	18	100	80
I	8	24 h[2]	7 d	9	100	573
I	9	24 h	8–9 d	12	100	653
I	10	24 h	5 d	12	79	522[3]
			6 d	13	21	
I	13–14	24 h	12 d	15	88	318[3]
			14 d	15	12	
II	18	Entire	2–8 h	18	100	65
III	18	Entire	1–2 h	18	100	65
IV	17	Entire	15 d	18	100	25
IV	18	Entire	22 h	18	100	40
V	17	Entire	14 d	18	100	25
V	18	Entire	24 h	18	100	40
VI	18	Entire	19 h	18	100	65
VII	17	4 h	20 d	18	0	60
VII	18	4 h	20 d	18	0	68

[1] Key to chemicals: (I) 3-bromo-4-nitrophenol; (II) o-ethyl-s-pentachlorophenyl thiocarbamate; (III) 3-trifluormethyl-4-nitrophenol; (IV) 3,4,6-trichloro-2-nitrophenol; (V) 2-bromo-4-nitrophenol; (VI) 2,5-dichloro-4-nitrophenol; (VII) 4-styrylpyridine.

[2] h = hours; d = days.

[3] Total number of specimens used in this experiment.

dying, however, the treated embryos continued to develop, but at a rate much slower than that of the controls. Development proceeded for 1 to 3 stages beyond the stage at time of treatment. Lampreys of Stages 17 and 18 exposed to 4-styrylpyridine were not killed but apparently only anesthetized. The compound had no visibly bad effect since all specimens recovered fully when placed in fresh water. This chemical had been used by Applegate, *et al.* (1957, *op. cit.*) on larvae for periods of 24 hours during their screening program without causing death (daily laboratory reports of Hammond Bay Fishery Laboratory, Millersburg, Michigan).

It would appear that chemical treatment of earlier stages (blastula through hatching) delayed development and led to death, but that prolarvae of Stage 17 will survive until such time as they enter Stage 18, whereupon death ensues, if they are still exposed to the larvicide. It appears also that blood formation is inhibited in prolarvae treated prior to Stage 15 (pigmentation).

The results of these experiments strongly suggest that chemical treatment of streams with larvicides for the control of sea lamprey would be most effective if carried out at leas 40 days (Piavis, 1961, *op. cit.*) after al spawning activity ceased. This period is th approximate time after fertilization for de velopment to Stage 18 under optimum con ditions. This timing would insure destructio of the more susceptible larval stages o lamphreys.

This work was accomplished while I wa employed as a Fishery Research Biologist a Hammond Bay Fishery Laboratory, Bureau of Commercial Fisheries, U. S. Fish and Wild life Service, Millersburg, Michigan, and a graduate student at Duke University.

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CONTRIBUTION

No. 161

Galveston Biological Laboratory
U. S. Bureau of Commercial Fisheries

Stabilization of the Nitrite Content of Sea Water by Freezing

This note reports the third of a series experiments designed to explore the effects of freezing on the stability of the emical content of sea water. Stabilization freezing is desirable since it eliminates need of adding chemical preservatives th accompanying impurities to the sam-. Collier and Marvin (1953) showed that the ratio of inorganic to organic phosphorus is stabilized by freezing. May (1960) demonstrated that freezing stabilizes the carbohydrate content of sea water for periods of up to 7 weeks. Similarly, it is shown that the NO_2^-–N content of sea water can also be stabilized.

The sea water used in this experiment

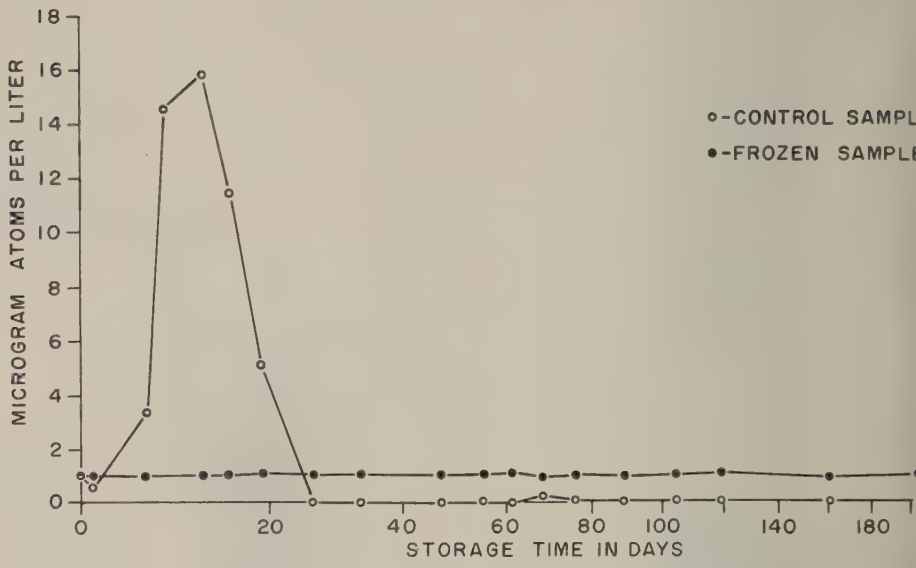

FIG. 1. Nitrite-nitrogen content of frozen and unfrozen seawater samples, plotted as a func storage time.

was filtered and then fortified with $NaNO_2$ to give an initial nitrite concentration of about 1.0 μg at./L. Approximately half of the treated water was dispensed into 120, 25 × 200-mm pyrex culture tubes equipped with polyseal caps. These samples were immediately frozen and stored at –18°C. The remainder of the treated water, about 3 gal, was stored at room temperature in a 5-gal pyrex carboy.

The method described by Bendschneider and Robinson (1952) was used to determine the nitrite concentrations in all samples. For the initial determination, subsamples from 10 tubes were analyzed immediately after they had been filled. Each determination thereafter consisted of analyses of 10 aliquots drawn from the storage container held at room temperature, and duplicate analyses on each of 5 frozen samples. At the beginning of the experiment, samples were analyzed twice a week. As the experiment progressed, the time interval between determinations was increased as shown in Figure 1.

A comparison of the two curves in Figure 1 shows the variability of the nitrite concentration in unfrozen sea-water sa and demonstrates the effectiveness of ing as a means of stabilization. A stat check ("F" test) of the frozen-sampl indicated that observed fluctuations well within the limits of the precision analytical method.

In view of these results, it is r mended that all sea-water samples on nitrite analyses are to be performed later date, be frozen as soon after coll as possible.

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The Relative Efficiency of Nylon and Cotton Gill Nets for Taking Lake Trout in Lake Superior[1]

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ABSTRACT

The change from cotton to nylon twine for gill nets in 1949–52 resulted in a sharp increase in the efficiency of the most important gear used for taking lake trout in Lake Superior, and, consequently, biased estimates of fishing intensity and abundance severely.

From early May to the end of September 1961, short gangs (2000 or 4000 linear feet) of cotton and nylon nets were fished in parallel sets for lake trout. A total of 343,000 feet of gill netting was lifted. Nylon nets were 2.25 times as efficient as cotton nets for taking legal-sized fish and 2.8 times as efficient for undersized lake trout. The average lengths of legal, undersized, and all lake trout taken in nets of the two materials did not differ greatly. The percentage of the catch which was undersized (less than 1.25 lb, dressed weight) was 20.8 in nylon nets and 17.7 in cotton. The relative efficiency of cotton and nylon nets showed no trend during the season. The efficiency ratio determined in this study was closely similar to that obtained by earlier workers.

Correction of estimates of fishing intensity and abundance for the greater efficiency of the nylon nets used since 1951 has not been attempted. The drastic decline of the lake trout fishery has forced fishermen to make changes in fishing practices in the past few years that cause new bias of an unknown extent to estimates of fishing intensity.

INTRODUCTION

The modern gill-net fishery in the upper Great Lakes differs greatly from the early fishery. The early gill nets were made of relatively coarse twine, had crude wooden floats, and were lifted by hand into open rowboats or sailboats. A long progression of improvements in equipment and methods has occurred since then. Power boats (first steam, then gas and diesel), enclosed and heated and with hulls capable of breaking through ice, have increased the length of season and the range of operation. Power lifters increased the amount of gear that could be handled, so that some fishermen lift as much as 10 miles (16 km) of net in a day; and recently fathometers and automatic pilots have assisted in location of suitable grounds and have reduced the need for manpower. The improved equipment enables fishermen to find their net buoys in fog or snow as far as 60 miles (96 km) from shore with uncanny ability.

Changes in the gill nets themselves have also been great. The structure and preparation of wooden floats were improved, and since 1925 aluminum floats have eliminated any depth limitation on fishing.[2] Increases in the efficiency of gill-net twine have kept pace with other improvements. Twine became finer

[1]Received for publication March 12, 1962.

[2]Nets are commonly fished in Lake Superior at depths down to 120 fathoms (220 m) and have been set in at least 150 fathoms (275 m). Usually few fish are taken below 120 fathoms.

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and more pliable and two changes in basic material have taken place. Du
the 1930's the softer, more elastic cotton thread replaced linen in most m
fisheries and in the late 1940's and early 1950's nylon twine in turn repla
cotton. The shift from cotton to nylon twine brought about the greatest si
increase in the efficiency of gill nets that has occurred. The earlier change f
linen to cotton did raise efficiency (we lack the quantitative data on the matt
but that increase was small compared to the one resulting from the later cha
from cotton to nylon.

The conversion from cotton to nylon twine in the large-mesh gill nets
Lake Superior[3] took place over the period 1949–52 — principally in 1950
1951. A change of gear at this time was peculiarly inopportune for the
ministrators and scientists who needed to follow the lake trout (*Salvel*
namaycush) fishery by analysis of statistics on effort and catch per unit of eff
The recent collapse of the lake trout fisheries of Lake Huron (Hile, 1949)
Lake Michigan (Hile *et al.*, 1951a) had created a strong market demand for L
Superior lake trout and had provided great incentive for increased fishing eff
At the same time, the population of sea lampreys (*Petromyzon marinus*) in L
Superior was expanding and its effects were soon to be felt (Hile *et al.*, 195
Then, at the beginning of a period of drastic decline in the fishery, the efficie
of the major fishing gear, the large-mesh gill net, was suddenly increased shar
Fishing intensity, as computed from the amount of gear lifted, was hencefo
greatly underestimated; and availability or abundance, based on catch per u
of effort, was to the same degree overestimated.

Extensive observations on the fishery were badly needed during the s
from nylon to cotton twine, but the Bureau was without the staff to make th
The only observations possible were those of Leo F. Erkkila[4] on a small num
of lifts off Marquette, Michigan, in 1950. His findings, mentioned briefly
Hile *et al.*, (1951b), indicated that nylon gill nets took about $2\frac{1}{2}$ times as m
lake trout as linen nets fished in the same gang.

The states were not asked to require fishermen to record the kind of gill-
twine on their monthly fishing reports during the period of change. It wo
have been highly indiscreet to solicit this information at a time when pressu
existed for legal restrictions on the use of nylon twine. Study of changes in
catch per unit effort of other trout-producing gears, to judge the increase
efficiency of gill nets after nylon twine came into use, was unproductive (H
1953). In spite of the known higher efficiency of nylon twine, the ratio of
catch per unit effort of set hooks to gill nets changed little with the conversion
suggesting that set hooks and gill nets exploited segments of the lake trout st
that were to some degree independent.

Estimates of fishing intensity and availability have, therefore, been ba
on greatly biased data since 1949. The Bureau was in position only to warn

[3]This paper applies specifically to gear and methods used in United States waters of L
Superior, but the fishery in Canadian waters is very similar.

[4]At that time Fishery Research Biologist in charge of the Bureau of Commercial Fishe
field station at Marquette, Michigan, and now Assistant Director, Sea Lamprey Control, of
Bureau's Biological Laboratory in Ann Arbor, Michigan.

to the direction of the bias and term it severe. The first opportunity to make a systematic study of the relative efficiency of cotton and nylon gill nets for taking lake trout in Lake Superior came in 1961. The present paper is a report on the results of that inquiry.

MATERIALS AND METHODS

Arrangements were made to have a commercial operator conduct the experimental fishing under supervision near Huron Bay (south-central Lake Superior). He was paid for fishing the cotton nets along with his own nylon nets.

New cotton nets totaling 9400 feet (2870 m) were made up for the experiment. Of this total, 5400 feet (1650 m) had a mesh of $4\frac{9}{16}$ inches (115.9 mm) and 60/6 twine, and 4000 feet (1220 m) had a mesh of $4\frac{5}{8}$ inches (117.5 mm) and 70/6 twine. The use of two sizes of mesh and twine was unavoidable — they were all that were readily available. Both sizes of mesh and twine were commonly used in 1946–49, however. The heavier 60/6 twine was fished most frequently in Wisconsin and the 70/6 twine in Michigan.[5] The nylon nets were of $4\frac{5}{8}$-inch mesh and 46/4 twine, the most common combination in use at the present time (1961). The cotton nets were hung on the one-half basis as was customary when they were the standard gear, and the nylon nets were hung on the five-eighth basis (8 feet of netting, flat mesh, on 5 feet of maitre) as is common now.

The cotton nets were fished in short gangs, usually 2000 or 4000 feet long (610–1220 m), set in a straight line approximately at right angles to the contours of the banks and roughly parallel to several similar gangs of nylon nets. Nets were left in the lake for 3 to 7 nights between lifts. In the spring when the water was very cold, they were usually left out 6 or 7 nights, but in late summer they could be left for only 3 nights. The fishing was done from early May through the end of September. All sets were made within the depth range of 8-38 fathoms (15-70 m). Whenever a gang of cotton nets was lifted, it was replaced by a gang of nylon nets regardless of the catch. The cotton nets were usually moved to another location along the same bank where they replaced a gang of nylon nets. After the middle of June, not all of the cotton nets could be fished simultaneously. They had to be reeled and dried periodically. Because of this periodic removal, and because there were more nylon gangs than cotton, it was not possible to alternate cotton and nylon gangs for all lifts. Catches were not consistently good or poor at any single location along the bank. It is believed that the system of replacing cotton gangs with nylon every lift (usually resetting the cotton gangs in place of nylon) made the data from the two gears closely comparable.

All lake trout caught in cotton nets and in nylon nets were measured (total length, to longest tip of the tail) and the total catches of legal-sized fish in each were weighed to the nearest $\frac{1}{2}$ pound (227 grams), dressed weight (viscera and

[5] In Michigan, some fishermen believed that finer cotton twine more than paid for the cost of more frequent replacement and used 80/6, 90/6, and even 100/6 thread in their nets. The nets used in this experiment cannot, therefore, be considered typical of the entire fishery in either Wisconsin or Michigan.

gills removed). Under the conditions of fishing it was impractical to k separate records for the two kinds of cotton nets. To all appearances the cat were approximately the same.

EARLIER COMPARISONS OF NYLON AND COTTON GILL NETS

Past studies of the comparative efficiency of nylon and cotton or linen tw have been based on several species and have yielded a variety of results (Ta I). Molin (1950, 1951) reported on parallel fishing with nylon and cot twine in Swedish lakes. Nylon twine caught between 2 and 3 times as muc several species, including whitefish (*Coregonus* sp.) and burbot (*Lota lota*), cotton. No trout were caught. Molin (1953) made another series of exp ments with cotton, spun nylon, and monofilament nylon. The poundage whitefish in spun nylon was 1.7 times that in cotton. Monofilament nylon not yet been used in the Great Lakes. Lawler (1950) found that nylon r

TABLE I. Summary of past observations on the relative efficiency of nylon and cotton gill r The "efficiency ratio" is the catch of the nylon nets divided by the catch of the cotton net

Author	Lake	Species	Efficiency ratio	
			By weight	By numb
Atton (1955)	La Ronge Last Mountain	Lake trout	*ca.* 2	...
Hewson (1951)	Winnipeg	Sauger, walleye, burbot	3	...
Lawler (1950)	Erie	Whitefish	3.2	...
Molin (1950)	Mälar	Principally roach[a]	...	3
Molin (1951)	Mälaren Siljan Brunträsket	Perch[b] and roach[a] Whitefish[c] Burbot	2 *ca.* 3 *ca.* 2	... ...
Molin (1953)	Storavan	Principally whitefish[c]	1.7	...

[a]Presumably *Rutilus rutilus.*
[b]*Perca fluviatilis.*
[c]*Coregonus*, species not given.

were 3.2 times as efficient as linen nets fished in the same gang for white (*Coregonus clupeaformis*) in Lake Erie. Hewson (1951) showed that nylon tw of 3-inch mesh was 3 times as efficient for sauger (*Stizostedion canadense*), wall (*S. vitreum vitreum*), and burbot as cotton in Lake Winnipeg. Atton (19 found that nylon nets of 5-inch mesh were about twice as efficient as cotton n of the same mesh for lake trout in Lac la Ronge and Last Mountain Lake. K nedy (1956), however, could find no evidence from the fishery statistics of Gr Slave Lake that nylon nets of $5\frac{1}{2}$-inch mesh were more efficient than cotton n of the same mesh size for either whitefish or lake trout. His conclusions w based on comparisons of two groups of fishermen operating in the same gene

area; one fished principally nylon nets and the other principally cotton nets. The two groups did not, however, use the same techniques of fishing. Consequently the Kennedy statement is not recorded in Table I.

Most studies, then, have indicated advantages for nylon over cotton ranging from a little less than two times to slightly more than three times. The one exception, just described, was not based on experimentation.

Atton (1955), Molin (1951, 1953), and Hewson (1951) all reported that the fish taken in nylon nets were somewhat larger than those taken in cotton nets. Kennedy (1956) mentioned that fishermen in Great Slave Lake generally believed that nylon nets take smaller fish than do cotton nets, but could find no evidence to support this belief.

Several commercial fishermen on Lake Superior suggested that the time of year the two materials were fished would affect their relative efficiency. Others suggested that if both were fished in the same gang, lake trout might lead along the cotton nets and be caught in the nylon. Most studies have not covered a sufficiently great time span to test the first suggestion, but the agreement between the findings of Lawler (1950) and Erkkila and those of other workers suggests that no great bias is introduced by fishing nets of both materials in the same gang.

CATCHES OF LEGAL AND UNDERSIZED LAKE TROUT IN NYLON AND COTTON GILL NETS

Most of the monthly records of take were based on substantial lifts of both kinds of gill nets. The amount of gear lifted ranged from 18,000 feet (5500 m) in July to 32,300 feet (9900 m) in May for cotton, and from 32,000 feet (9800 m) in July to 50,000 feet (15,300 m) in August for nylon (Table II). The catch per

TABLE II. Amount of cotton and nylon gill nets lifted, pounds of legal-sized (1¼ lb dressed) lake trout caught, catch per unit effort, and comparative efficiency of nylon and cotton twine. (10,000 feet = 3050 m)

Month (1961)	Number of feet of net lifted		Pounds of legal-sized lake trout caught				Efficiency ratio
			Total		Per 10,000 feet of net		
	Cotton	Nylon	Cotton	Nylon	Cotton	Nylon	
May	32,300	40,800	94.0	250.0	29.1	61.3	2.1
June	22,000	41,800	45.5	249.5	20.7	59.7	2.9
July	18,000	32,000	34.0	114.0	19.1	35.5	1.9
August	30,000	50,000	107.5	424.5	35.8	84.9	2.4
September	32,000	44,000	111.0	330.0	34.7	75.0	2.2
Total	134,300	208,600	392.0	1,368.0	29.2[a]	65.6[a]	2.25[b]

[a]Based on grand totals.

[b]The unweighted mean of the monthly values was 2.30.

10,000 linear feet of net lifted ranged from 19.1 lb in July to 35.8 lb in Aug for the cotton nets and from 35.5 lb in July to 84.9 lb in August for the ny nets (28.4–53.2 kg/10,000 m in July, 52.8–126.3 in August). Although quality of the fishing varied considerably from month to month, no trend apparent in the comparative efficiency of the two materials. Nylon nets cau from 1.9 to 2.9 times the poundage of legal-sized lake trout taken by cotton per unit effort in different months, but the variation of the ratio was rand The most valid figure for the comparative efficiency is probably the ratio of catches per unit effort in nylon and cotton nets as determined from the combi poundages for the 5-month period. For this period the catch per unit effor legal-sized lake trout in nylon nets was 2.25 times that of the cotton nets. unweighted mean of the monthly efficiency ratios (2.30) had almost the sa value. A figure of $2\frac{1}{4}$, then, constitutes a sound estimate of the ratio. T value is only slightly below the figure of $2\frac{1}{2}$ determined by Erkkila for nylon n fished in the same gang with linen nets. Apparently, leading of fish along linen nets to the nylon nets in the same gang did not materially influence catch in nylon gear. Cotton twine probably is slightly more efficient than li twine.

The relative efficiency of nylon and cotton for catching undersized lake tr is of some interest because the regulations of all administrative agencies on L Superior specify minimum sizes for lake trout as well as minimum mesh si for gill nets. The number of undersized trout caught varied greatly from mo to month, but the comparative efficiency of the two materials again showed consistent trend (Table III). For the 5-month period, nylon nets averaged trout of sub-legal size per 10,000 feet (3050 m) of net lifted, and cotton n

TABLE III. Number of undersized lake trout caught in each month and number taken per effort in nylon and cotton nets. (10,000 feet = 3050 m)

Month	Number of undersized trout				Efficienc ratio (by numb of fish)
	Total		Per 10,000 feet		
	Nylon nets	Cotton nets	Nylon nets	Cotton nets	
May	27	6	6.6	1.9	3.5
June	58	12	13.9	5.5	2.5
July	30	11	9.4	6.1	1.5
August	20	3	4.0	1.0	4.0
September	27	3	6.1	0.9	6.8
Total	162	37	7.8[a]	2.8[a]	2.8[b]

[a]Based on grand totals.

[b]Because of the small numbers of fish taken in cotton nets in some months, presentation of unweighted mean of the ratios is not desirable.

veraged 2.8. Nylon nets were, therefore, about 2.8 times as efficient for under-ized trout as cotton nets, as compared with 2.25 times for legal-sized trout. ince the undersized trout were not weighed, it was not possible to calculate the omparative efficiency of nylon and cotton for all sizes of fish in terms of poundage.

SIZE OF LAKE TROUT CAUGHT IN NYLON AND COTTON GEAR

As was mentioned in a previous section, most comparisons of nylon and otton nets have shown the average size of fish taken in nylon nets to be larger han that of fish caught in cotton nets. This study failed to indicate such a elation. The average weight of legal-sized trout (greater than 1.25 lb or 0.57 g, dressed) taken in nylon nets did not differ significantly (was 0.03 lb less) rom that of fish taken in cotton nets (Table IV). Although the total number f fish taken in cotton nets was small, the mean weight of individual legal trout aken in cotton gear was the greater in 4 of the 5 months. The one exception ccurred in the month of smallest total catch.

TABLE IV. Average dressed weight, in pounds, of legal-sized lake trout (1¼ lb dressed, or larger) taken in nylon and cotton nets, May–September, 1961. (1 lb = 454 g).

Month	Nylon nets	Cotton nets	Difference
May	2.03	2.19	0.16
June	1.96	1.98	0.02
July	2.03	1.72	−0.31
August	2.43	2.44	0.01
September	2.44	2.52	0.08
Average	2.22	2.25	0.03

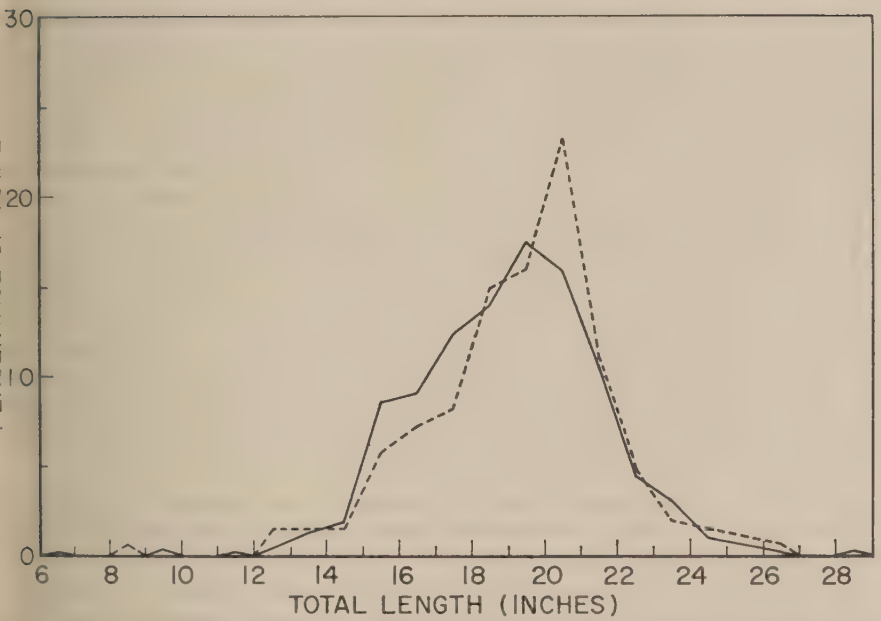
Among lake trout of all sizes (both legal and undersized) the cotton nets ook longer fish (average length 19.2 inches or 487 mm) than did nylon nets 18.9 inches, 480 mm) — see Table V. The differences between the two gears n the mean length of fish of legal or below legal size were slight, but the nylon nets ere relatively the more effective in the entanglement of smaller lake trout in ne range 14.0 to 17.9 inches (354–455 mm) — (Fig. 1). Cotton nets were elatively more effective for fish in the range 20.0 to 20.9 inches (508–531 mm). he percentage of undersized lake trout in the catch of nylon nets was 20.8 as ompared with 17.7% in cotton nets. These figures give support to the evidence f the previous section on the relatively greater ability of nylon nets to take ndersized trout (efficiency ratio, favoring nylon, of 2.8 for undersized fish ompared to 2.25 for legal-sized lake trout). Nylon twine's greater selectivity or lake trout several inches shorter than the modal frequency is a reflection of s greater capacity for entangling various head and body parts rather than its bility to hold gilled fish of that size. Few, if any, lake trout less than 18 inches

TABLE V. Total-length distributions, average lengths, and percentage undersized, for lake trout taken in nylon and cotton nets (1 inch = 2.54 cm).

Length interval (*inches*)	Nylon nets		Cotton nets	
	Number of fish	Percentage	Number of fish	Percentage
6.0– 6.9	1	0.1	...	...
7.0– 7.9	...	...	...	...
8.0– 8.9	...	...	1	0.5
9.0– 9.9	2	0.3	...	...
10.0–10.9	...	...	...	...
11.0–11.9	1	0.1	...	...
12.0–12.9	3	0.4	3	1.4
13.0–13.9	10	1.3	3	1.4
14.0–14.9	14	1.8	3	1.4
15.0–15.9	66	8.5	12	5.7
16.0–16.9	70	9.0	15	7.2
17.0–17.9	96	12.3	17	8.1
18.0–18.9	107	13.8	31	14.8
19.0–19.9	135	17.3	33	15.8
20.0–20.9	122	15.7	48	23.1
21.0–21.9	81	10.4	23	11.0
22.0–22.9	34	4.4	10	4.8
23.0–23.9	23	3.0	4	1.9
24.0–24.9	7	0.9	3	1.4
25.0–25.9	4	0.5	2	1.0
26.0–26.9	1	0.1	1	0.5
27.0–27.9	...	...	...	...
28.0–28.9	1	0.1	...	...
Total	778	100.0	209	100.0
Average length				
Legal	19.8	...	20.1	...
Undersized	15.4	...	15.2	...
All fish	18.9	...	19.2	...
Percentage Undersized	...	20.8	...	17.7

(457 mm) long have a great enough girth to be held in nets of mesh $4\frac{5}{8}$ in (118 mm), but they are caught by the teeth, head bones, or fins.

Atton (1955) showed that the principal difference between the selectiv of nylon and cotton nets was that nylon nets took a greater proportion of from the upper end of the size range taken by both materials. Selectivity or lower end of the size range was nearly identical for the two twines. This obse tion applied to catches of ciscoes (*Leucichthys* sp.), whitefish, and walleyes t in nets of 1.5, 2 and 5 inches mesh (38, 51 and 127 mm). Almost exactly opposite appears to be true for lake trout. The difference in selectivit principally in the 6- or 7-inch interval immediately below the modal frequenci not at either end of the range. The number of fish longer than 22 inches mm) is so small that evaluation of net selectivity for the larger lake trout is possible. The slightly higher percentage representation of lake trout gre than 24 inches (610 mm) long in cotton nets must be considered insignifican



IG. 1. Percentage length distribution of lake trout caught in nylon and cotton gill nets. *Solid line*, nylon nets; *broken line*, cotton nets.

In former years, before sea lamprey depredations drastically reduced the umbers of larger lake trout, fish up to 30 inches (762 mm) long were common n the catches of nets of $4\frac{5}{8}$-inch (118 mm) mesh, and the proportion of fish 22 to 0 inches (558–762 mm) fish was much greater than it is now. In late summer nd fall, concentrations of large trout were great enough that nets of mesh $5\frac{1}{2}$ nd $6\frac{1}{2}$ inches (140 and 165 mm) were commonly fished. Obviously, the percent-ge of undersized fish was considerably lower in the former fishery.

INTERPRETATION OF RECENT LAKE TROUT STATISTICS

The close agreement between our finding that nylon gill nets are 2.25 times s efficient as cotton nets for taking legal-sized lake trout in Lake Superior and rkkila's earlier observation of a 2.5-fold advantage of nylon over linen twine, ives evidence that both studies yielded reasonably dependable results. The eneral agreement of the Lake Superior studies with those of other investigators ends additional support to this view. It would seem then that the value 2.25 or the efficiency ratio could be used to "correct" the records of fishing effort for ill nets beginning in 1951 (when nylon had almost completely replaced other wine). This correction would automatically adjust the catch per unit effort or gill nets and thus shift the indices of both fishing intensity and abundance to evels fairly comparable to those for years prior to use of nylon nets.

The correction of gill-net records might well be valid for the early 1950's, since then other biasing influences have developed. A trend began tow concentration of fishing effort on the better grounds in the best seasons. poorer fishermen were forced to cease operations altogether and the be fishermen turned to fishing other species during slack periods. This tr continued steadily until, by 1959, the lake trout fishery was a part-time opera limited to the winter and spring months for all but a few fishermen. In 1 and 1961 only one fisherman on the entire United States shore of Lake Supe fished for lake trout steadily through all the summer and fall months. Abunda indices calculated from an annual average catch per unit effort on a full-t fishery are not comparable with those from the present part-time fishery. Th fore, even though we can now feel confidence in a value for the efficiency r of nylon and cotton gill nets fished for lake trout, correction of recent lake tr statistics still would yield undependable figures. The changes in the fish have been great and further changes are to be anticipated as sea lamprey con and lake trout rehabilitation continue in the years immediately ahead.

When lake trout stocks have again attained some measure of stability fishery may well become re-established under conditions considerably differ from those prevailing in former years. For example — either the total catch total fishing effort may be controlled; commercial sport trolling may increas a point where it takes a significant part of the total catch; minimum mesh si size limits, and season closures may be altered. After the fishery is re-establish a new base period of reference should be established to follow fluctuations.

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ects of Gamma Radiation on Two Decapod ustaceans, *Palaemonetes pugio* and *Uca pugnax*[1]

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ABSTRACT

Two decapod crustaceans, the grass shrimp, *Palaemonetes pugio*, and the fiddler crab, *Uca pugnax*, were subjected to graded doses of cobalt-60 gamma radiation. The dose required to kill 50% of the animals within 7 days, 14 days, and 30 days was calculated. The LD_{50} 30 days of *Palaemonetes pugio* was about 1,500 r and the LD_{50}/30 days of *Uca pugnax* was about 8,000 r. Females of *P. pugio* which were ovigerous at the time of irradiation either released their eggs unhatched, or, in the one case in which hatching occurred, all larvae died within three days. Prolongation of the intermolt period was observed in *U. pugnax* individuals irradiated at the lower dosages.

Introduction

pite of the increased interest in the ef- f ionizing radiations on living mate- th the advent of atomic power, little on has been given to the sensitivity rine organisms to these radiations. gs and sperm of the sea urchin, *Arba- nctulata* have been subjected to X by various investigators, Henshaw , Evans (1947), and Barron, *et al* , among others. Lynch (1958) dis- the effect of X rays on the larvae of ecies of the bryozoan *Bugula*; Bon- nd Palumbo (1951) have determined hal dosages of X rays for the brine , *Artemia salina*, the amphipods *Cal- laeviusculus* and *Allorchestes angus-* d the marine snail, *Thais lamellosa*; (1957) has shown that the oyster *rosalpinx cinerea*, can tolerate high s of high frequency X rays. The liter- appears to be devoid of information ning the responses of the higher crus- s to doses of ionizing radiation.

present paper is a report on experi- that were undertaken with the ob- of determining the lethal dosages of a radiation, particularly the doses at 50 per cent succumb (LD_{50}), for two d crustaceans, the fiddler crab, *Uca pugnax* and the grass shrimp, *Palaemonetes pugio*.

The author wishes to express his appreciation to Dr. Donald J. Fluke of Duke University for allowing the use of the Duke University cobalt-60 source.

Methods

In the present study, all the irradiations were carried out at the Duke University Marine Laboratory, Beaufort, N. C. The Duke University radiation facility consists of a cobalt-60 source of approximately 300 curies with a dose rate, at the time of these experiments, of 1,950 roentgens (r) per minute. The sample chamber is a cylindrical cavity 2¼ inches in diameter by 14 inches deep.

Three hundred and fifty *Palaemonetes pugio* were taken at random from a group of several hundred, and placed in fourteen 2½ gallon glass aquaria, 25 individuals per aquarium. No attempt was made to select animals by size or sex. The aquaria were divided into seven groups of two aquaria each. Six of these groups each received a different dosage of gamma radiation, the seventh group was maintained as a control.

All animals were irradiated in 50 ml screw cap test tubes with the cap in place. Only one tube, containing 5 individuals, could be irradiated at a time. The 50 animals in a group were carried to the source (a distance of approximately 1000 yds.) in

work reported was carried on as part of a tive project of the U. S. Bureau of Com- Fisheries and the U. S. Atomic Energy ssion.

two aquaria. Five animals were taken from an aquarium and placed in a test tube half full of sea water. The tube was irradiated, and the animals were returned to another aquarium. This procedure was repeated until all 50 animals in a group had received the same dosage level. The length of time which any animal spent in the tube was no more than 1 to 2 minutes longer than the actual time of exposure in the source. Exposure times were selected as a matter of convenience and were 0.5, 1.0, 2.5, 5.0, 10.0, and 20.0 minutes, with corresponding dosages of 975, 1,950, 4,875, 9,750, 19,500, and 39,000 roentgens.

When test objects are irradiated in water, the possibility of an indirect effect through the production of some toxic substance in the water should be taken into account. Evans (1947:107–8) believed this indirect effect to be due to the production of hydrogen peroxide, and Barron (1949:55) has postulated that the formation of stable organic peroxides in sea water contributes to the toxic effects of ionizing radiations. Evans found that no detectable hydrogen peroxide was produced in sea water at dosages below 100,000 r and Barron found that no stable organic peroxides were detectable in sea water that had received less than 50,000 r. To minimize any indirect effect from irradiated water, the highest dosage (39,000 r) for *P. pugio* was given in two 10 minute exposures, two hours apart. The animals were placed in tubes, irradiated for 10 minutes, and returned to aquaria as described above. After two hours, during which time the water in the aquaria had been changed, the procedure was repeated. The highest dose to the water in which any of the animals were irradiated was 19,500 r. This level would probably not produce enough of any toxic substances in sea water to affect the animals.

In an attempt to avoid considering the factor of handling and confinement in the test tubes as a cause of mortality, the controls were handled in a manner similar to the 39,000 r group, which received the most handling of any of the treated animals. The controls were removed from aquaria, placed in test tubes, 5 individuals per tube, allowed to remain for 10 minutes, and returned aquaria. After two hours the procedure w repeated.

The irradiation procedure for *U. pugn* was the same as for *P. pugio*, with the f lowing exceptions. No water was added the test tubes in which the animals w irradiated and the 39,000 r dose was giv in one 20 minute exposure. The *U. pugn* controls were placed in tubes and allowed remain for 20 minutes before being return to aquaria. The 1,950 r dosage level gro was omitted in the *Uca* experiments. T only reason for this was that the time which the source was available did not p mit giving this dose. *U. pugnax* were ma tained in 2½ gallon rectangular aqua containing approximately ½ inch of s water, with 25 individuals in each aqu ium. As in the case of *P. pugio*, each treat group, and the control group, consisted 50 animals, randomly selected from a la population. Both species were fed tissu of the ribbed mussel, *Modiolus demiss* The number of individuals surviving in ea aquarium was recorded each day, and, in t case of *U. pugnax*, a record was made of t number of individuals which had molt Some of the irradiated groups of *P. pu* contained ovigerous females. These w segregated to see if the eggs would hat and the larvae develop.

Karber's method, as outlined by Irw and Cheeseman (1939:578) was used to c culate the LD_{50} at 7, 14, and 30 days *P. pugio* and *U. pugnax*. Following Irw and Cheeseman's (1939:578–80) meth the standard errors of the LD_{50}s were c termined.

Results

Palaemonetes pugio

The cumulative mortality of the vario groups of *P. pugio* is shown in Fig. 1. shows that the 975 r group is very simil to the controls during the first 28 days. the dosage groups above 975 r, essentia all the animals were dead by the 28th da At 39,000 r, 50% of the animals died with 6 days; at 19,000 r 50% died within 8 da at 9,750 r, within 9 days; at 4,875 r, wit

0 days; and at 1,950 r, 50% died within 11 ays.

Since it is not possible to maintain con- ols for long periods without mortality, the ffects of dosages that do not kill within bout 30 days are difficult to evaluate. The ifferences between the 975 r group and the ontrols became more apparent after the rst 40 days following irradiation. At this me, all of the females in the control group ad become ovigerous, whereas none of the radiated females produced eggs at any me during the experiment. Mortality in ie control group reached 50% in 105 days, hile 50% of the 975 r group died within 4 days. After 125 days, mortality had risen 60% in the controls and 88% in the ir- adiated animals.

Using the method outlined by Irwin and heeseman (1939), with a correction for ontrol mortality, the dose required to kill 0% of the animals within 7 days, 14 days, nd 30 days was calculated. Table 1 shows, or *P. pugio*, the logarithm of the LD_{50} at , 14, and 30 days, its standard error, the ctual LD_{50}, and the limits of error (P = .95 and P = 0.99). Limits of error (P = .99) of, for example, 84–119% mean that 9 times out of 100 the result would lie be- ween 84 and 119% of its true value.

Three females in the 4,875 r group were vigerous at the time of irradiation. These ere segregated in large finger bowls to see the eggs would hatch. All three females eleased their eggs unhatched within 4 days fter being irradiated. Large numbers of *P. ugio* larvae have been hatched and reared t this laboratory from females which had ot been irradiated. In no case have the eggs een observed to become detached from the leopods of the female before hatching oc- urred.

In the 9,750 r group, one female was ovi- erous at the time of irradiation. She was laced in a large finger bowl of filtered sea ater and 4 days following irradiation the ggs hatched, releasing about 200 normal ppearing zoeae. One hundred of these arvae were removed and placed in individ- al compartments in plastic boxes to see if hey would develop normally. All zoeae died ithin three days after hatching and before

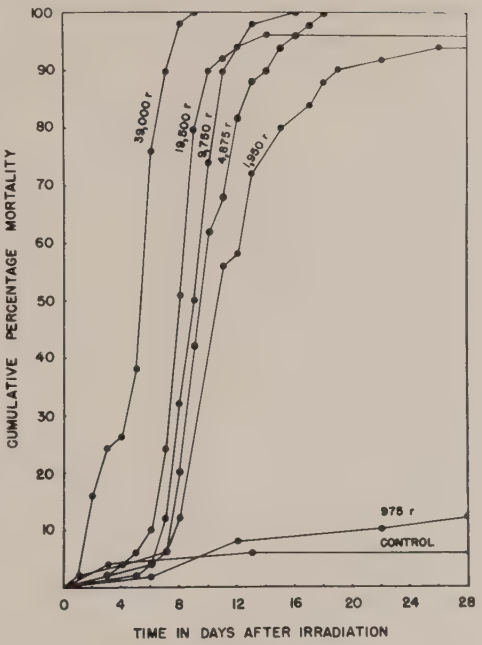

Fig. 1.—Daily cumulative percentage mortality of *Palaemonetes pugio* subjected to graded doses of cobalt-60 gamma radiation.

TABLE 1.—The LD_{50} of Co^{60} gamma rays and its error for *Palaemonetes pugio*.

Time in days	Log LD_{50}	S.E. of log LD_{50}	LD_{50} in Roentgens	Limits of error %	
				P = 0.95	P = 0.99
7	4.33724	0.040	21,739	83–120	79–127
14	3.37244	0.044	2,357	82–122	77–130
30	3.16299	0.029	1,455	88–144	84–119

any individuals had undergone the first molt. At first glance it appears odd that eggs which had received a dosage of 9,750 r would hatch whereas eggs which had received only half this dosage, or 4,875 r, would fail to hatch. It must be remembered, however, that the stage of development of the eggs in the 4875 r group was not determined. Previous experiments at this laboratory have shown that *P. pugio* eggs normally hatch about 15 days after being attached to the pleopods. Since the eggs of the female from the 9,750 r group hatched 4 days after being irradiated, these eggs were in the late developmental stages at the

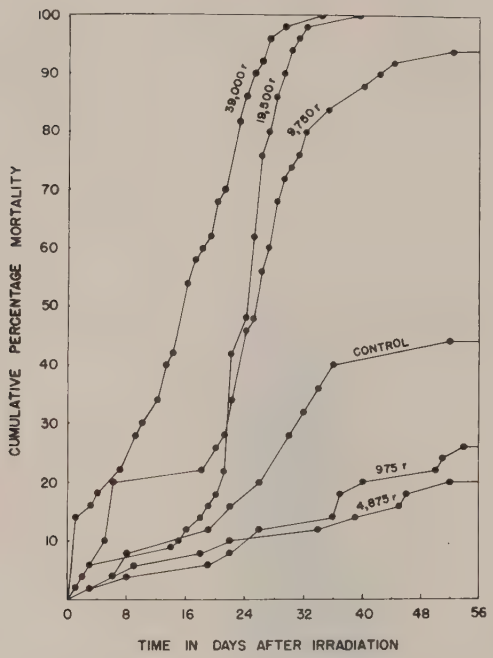

Fig. 2.—Daily cumulative percentage mortality of *Uca pugnax* subjected to graded doses of cobalt-60 gamma radiation.

time of irradiation. There is considerable evidence from other animals that radiosensitivity of the embryo decreases with age (Rugh, 1954; Wilson, 1954; Russell and Russell, 1954; Welander, 1954; Bonham, 1955). It would seem that the eggs of the females in the 4,875 r group were in a more sensitive and probably at an earlier developmental stage than those in the 9,750 r group.

Uca pugnax

Fig. 2 shows the cumulative mortality in the various dosage groups of *U. pugnax* for 56 days following irradiation. It is apparent that *U. pugnax* is less radiosensitive than *P. pugio*, under the conditions of this experiment. At 39,000 r, 50% of the animals died within 16 days; at 13,500 r, 50% died within 24 days; and at 9,750 r, 50% died within 26 days. Individuals in the 39,000 r and 19,500 r groups were very sluggish and ate little or nothing after being irradiated. In the 9,750 r group there was a slight reduction in activity, but food was accepted readily. The most striking feature of F is that mortality in the 975 r and 4,8 groups is less than in the controls. *U. pu* is cannibalistic, and this is especially if they have access to newly molted ind uals. In the present experiments the ani were not segregated and, when an ind ual molted, it was usually eaten by others. At dosages of 9,750 r and abov molting occurred and none of the morta recorded are the result of cannibalism dosages of 4,875 r and below, molting occur and virtually all mortalities are result of cannibalism. The differences tween the two lower dosage groups and controls in Fig. 2 then, is actually a re tion of the differences in the molting quency of the three groups. This differ is more clearly illustrated in Fig. 3 w shows the cumulative percentage molt the 975 r and 4,875 r groups and the cont As previously stated, no molting occu in the higher dosage groups. From the of Fig. 3 the mean intermolt periods o three groups can be calculated. For

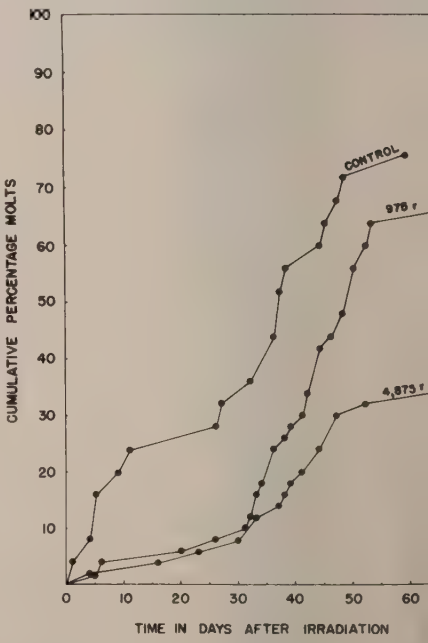

Fig. 3.—Daily cumulative percentage mo *Uca pugnax* subjected to cobalt-60 gamma tion.

ntrols the mean intermolt period is 95 ays; for the 975 r group, 106 days; and for ie 4,875 r group, 212 days.

Treating the *U. pugnax* data by the ethod of Irwin and Cheeseman (1939), the ose required to kill 50% of the animals ithin 7 days, 14 days, and 30 days was alculated. Since mortality in the two lower osage groups was the result of cannibalism, nd not radiation effects *per se*, the mor- ality of these groups and the controls was aken as zero in the calculations. Table 2 ows, for *U. pugnax*, the logarithm of the LD_{50} at 7, 14, and 30 days, its standard rror, the actual LD_{50}, and the limits of rror (P = 0.95 and P = 0.99).

Discussion and Conclusions

It has been generally agreed that inverte- rates can survive much higher dosages of nizing radiation than vertebrates. Wich- erman and Figge (1954) give an LD_{50} of 40,000 r for *Paramecium caudatum*. Bon- am and Palumbo (1951) give the following LD_{50} dosages: for the snail, *Radix japonica*, 0,000 r at one week; for the snail, *Thais amellosa*, 13,000 r at 160 days; for the mphipods, *Calliopius laeviusclus* and *Al- orchestes angustus*, 10,000 r at 5 weeks; and or soaked eggs of the brine shrimp, *Artemia alina*, 20,000 r at 10 days. Hargis (1957) ives the lethal dose for the oyster drill, *Urosalpinx cinera*, as from 24,000 r to 27,000 . King and Wilson (1955) report a 60% ortality in two weeks in *Drosophila mela- ogaster* exposed to 60,000 r.

The above figures are in rather sharp ontrast to the relatively low dosages re- uired to produce 50% mortality in some ertebrate animals. The following are some 0 days LD_{50}s listed by Bacq and Alexander 1955:220) from various sources; newt, .000 r; tortoise 1,500 r; fowl 1,000 r; rab- it, 750 to 825 r; rat, 590 to 970 r; mouse 00 to 650 r; and man 400 to 500 r.

It should be noted that these comparisons re made without benefit of information on he sampling error or how the LD_{50}s were omputed. In addition, the responses of rganisms to ionizing radiations are influ- nced by the energy of the radiation, the ose rate and other physical conditions of

TABLE 2.—The LD_{50} of Co^{60} gamma rays and its error for *Uca pugnax*.

Time in days	Log LD_{50}	S.E. of log LD_{50}	LD_{50} in Roentgens	Limits of error %	
				P = 0.95	P = 0.99
7	4.70510	0.039	50,710	84–119	79–126
14	4.65238	0.044	44,910	82–122	77–130
30	3.91432	0.046	8,209	81–123	76–131

the experiment, and the metabolic activity of the organisms at the time of exposure. For these reasons, results obtained by different authors are seldom strictly comparable, although they do serve to show the relative sensitivity of various groups of organisms.

In the present experiments, *P. pugio*, with an LD_{50}/30 days of about 1,500 r exhibits a radiosensitivity close to that of some cold-blooded vertebrates, while *U. pugnax*, with an LD_{50}/30 days of about 8,000 r is considerably more resistant to ionizing radiation. In the three higher dosage groups the length of time necessary to achieve 50% mortality in *U. pugnax* was 2.6 to 3.0 times that of *P. pugio*. There is some indication that there may be less difference between the dose necessary to kill 50% of the animals than there is between the length of time required for the lethal effect to appear.

In the present state of our knowledge these differences in radiosensitivity between different groups of organisms, and even between similar species within a group, cannot be explained. Hypotheses have been advanced relating differences in radiosensitivity to differences in enzyme systems containing heavy metals; to differences in amounts of amino acids present in the internal environment; to differences in oxygen tension in the tissues; and to the presence of quantities of carboxylic acids, such as formic acid in some insects (Bacq and Alexander, 1955:225). Any of these hypotheses could well form the basis of an experimental study, and further research with invertebrates is highly desirable.

It was not the purpose of the present investigation to study in any detail the effect of damaging but non-lethal exposures to radiation, but certain effects besides death were noted. All of the females in the *P.*

pugio control group became ovigerous during the course of the experiments, whereas none of the females in any of the irradiated groups produced eggs at any time during the period of observation. Three females in the 4875 r group were ovigerous at the time of irradiation but within four days after exposure all had released their eggs unhatched. In the 9750 r group one female was ovigerous at the time of exposure. These eggs hatched four days following irradiation but all larvae died within three days after hatching. It should be noted here that different developmental stages of the same species almost invariably display different degrees of radiosensitivity. There appears to be a direct relationship between radiosensitivity and mitotic activity, and adults of a species are generally the most resistant to ionizing radiations.

Some observations were made on the frequency of molting in the various groups of *U. pugnax*. At dosages of 9,750 r and above, no molting occurred. At dosages of 4,875 r and below, molting did occur and the mean intermolt periods were calculated. For the 975 r group the mean intermolt period was 106 days and for the 4,875 r group, 212 days, as compared with a mean intermolt period for the controls of 95 days.

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The information gained from this initial offshore tagging program is proving useful in the preparation and planning for the two large scale tagging programs which will concentrate on offshore populations south of the Alaska Peninsula from Kodiak to Unimak Pass during 1961.

PROBLEMS AFFECTING THE ALASKA HERRING INDUSTRY

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U. S. Fish and Wildlife Service
Auke Bay, Alaska

Problems affecting the Alaska herring industry can be placed in three categories: economic, political, and biological.

Of these, concern presently centers on economic factors. Rapid growth of Peruvian fish meal production since 1957 has depressed progressively a previously stable world market. Alaskan producers with high labor and transportation costs have difficulty in competing with great volumes of lower priced foreign and domestic products. Increased activity of Japanese and Russian reduction fleets tends to compound this problem.

An international meeting, sponsored by the FAO, concerned with fish meal and oil production was held in March, 1961. Results of the meeting indicated that a greater human consumption of fish meal and flour was needed, because it would provide ready protein for protein deficient areas and a stimulant for sagging world markets.

The political position of Alaska herring processors has been poor. Employing out-of-state-workers and contracting to Seattle boats has not been received favorably by resident Alaskans. Lack of understanding of herring-salmon relationships, especially by members of the salmon trolling industry has led to bitter controversy. Recent findings, however,

have eased these tensions to some extent.

Many gaps remain in the knowledge of herring biology: factors causing differential mortality among year classes are little understood; mortality rates for individual year classes are not well established; and the actual extent of Alaskan herring stocks has not been adequately defined. Understanding such problems is basic to proper management of the Alaska herring resource and for expansion of a valuable industry operating at a maximum sustained level.

COMMON PROBLEM -- COMMON FISH NAMES

Homer Circle
Daisy Manufacturing Company
Rogers, Arkansas

Gertrude Stein would say, "A bass is a bass is a bass." Fishermen say, depending on locale, "It's a black bass, green bass, redeye bass, linesides, bronze bass, tiger bass, bigmouth bass, largemouth black bass, Oswego bass, trout, etc."

Dozens of colloquial names apply to this most popular of North American sport fishes. As a result, when a fisherman in Louisiana tells a visiting bass fisherman from Ohio that a certain bayou is full of trout, the Buckeye is sure to take along the wrong fishing tackle for those trout are largemouth bass.

But the confusion goes much deeper. Only two fishermen in 20 can definitely identify the largemouth, smallmouth, and spotted basses. We must tell these two learned fishermen that the largemouth, smallmouth, and spotted basses are not basses at all, but members of the sunfish family.

Then we must further befuddle them by telling them that there are only three true basses; the white bass, yellow bass, and the white perch.

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BREEDING CYCLES AND BEHAVIOR OF LAYSAN AND BLACK-FOOTED ALBATROSSES

Dale W. Rice and Karl W. Kenyon

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pp. 517–567
Made in United States of America

Laysan Albatross on the right illustrates the Gawky-look immediately preceding Billing. KWK 57-2-13.

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BREEDING CYCLES AND BEHAVIOR OF LAYSAN AND BLACK-FOOTED ALBATROSSES

Dale W. Rice and Karl W. Kenyon

During the 1956–1957 and 1957–1958 seasons, we conducted intensive studies on the breeding cycles and breeding behavior of the Laysan Albatross (*Diomedea immutabilis*) and the Black-footed Albatross (*D. nigripes*), as part of a comprehensive study of their biology. Behavior of unemployed birds is not considered in this paper. In a previous publication (Rice and Kenyon, 1962) we treated the breeding distribution and numbers of these birds. Population dynamics and distribution at sea, based on a large-scale banding program, will be treated in a later report. Nesting studies were conducted at Midway Atoll, in the Hawaiian Islands. Rice was in the field from 17 November 1956 until 21 July 1958; Kenyon from 29 December 1956 until 26 June 1957.

Aside from Richdale's (1939, 1942, 1950, 1952) intensive 16-year study of a small colony of Royal Albatrosses (*D. epomophora*), Sorensen's (1950a, 1950b) work on the Royal Albatross and the Light-mantled Sooty Albatross (*Phoebetria palpebrata*), and Rowan's (1951) observations on the Yellow-nosed Albatross (*D. chlororhynchos*), no year-round studies of albatrosses have been conducted. Our studies, although extending over a much shorter period of years than Richdale's, have one advantage in the far greater number of birds under observation.

Our data are reasonably complete through the early post-guard stage (terms relating to breeding behavior follow the usage of Richdale, *op. cit.*). Other duties prevented our making a detailed study of the remainder of the nestling period. Many other aspects of albatross biology can be revealed only by studies extending over many years. We hope that the gaps in our work will indicate to future workers the most profitable fields of investigation, and that our descriptive and experimental studies will lay the groundwork for more detailed experimental analyses of the various phases of the breeding cycle.

The only previous ornithologist to record quantitative observations on

marked birds was Robert Sheehan (*in* Richdale, 1952). Other published accounts present only general observations on, or cover only certain aspects of, the breeding cycle. These include the successive contributions of Rothschild (1893), W. K. Fisher (1904, 1906), Richards (1909), Dill and Bryan (1912), Bartsch (1922), Hadden (1941), H. I. Fisher and Baldwin (1946), H. I. Fisher (1948, 1949), Bailey (1952, 1956), and Richardson (1957). Recently, experimental studies have been made on salt balance by H. and M. Frings (1959), and on thermoregulation by Howell and Bartholomew (1961); the Frings (1961) have published a few statistical observations.

MATERIALS AND METHODS

The basic data concerning the breeding cycle were obtained primarily from two study plots on Sand Island. During the 1957–1958 season, 116 pairs of marked Laysan Albatrosses and 39 pairs of marked Black-footed Albatrosses, respectively, nested on these two plots. The nests were checked twice daily, at 08:00 and 18:00 (sun noon Midway time—GMT minus 11 hours—is approximately 13:00). (For statistical purposes, we have regarded the time interval as 12 hours, although examinations were alternately 14 and 10 hours apart.) In addition, six experimental study plots containing 419 Laysan Albatross nests, and one control plot, containing 164 Laysan nests, were under frequent observation on Sand Island throughout both the 1956–1957 and 1957–1958 nesting seasons. Other incidental studies were made on nests outside the major study areas, on both Sand and Eastern islands.

All nests under regular observations were either marked with a numbered wooden stake (Figure 1) or were plotted on large-scale maps. Eggs were marked with pen, pencil, or dye. Birds were permanently marked with standard U.S. Fish and Wildlife Service numbered aluminum bird bands, size 7B. To avoid disturbing incubating birds, each sex was distinctively marked with Rhodamine B red dye—red "caps" on females, red "mustaches" on males.

The sex of all marked nesting birds on the permanent study plots was determined by cloacal examination. Up to about 10 days after egg laying, the female of the pair can be distinguished by her distended cloaca. In addition, females are, on the average, slightly smaller and of more delicate build than their mates, with shorter, more slender beaks and smaller heads. Although measurements of 13 males and 19 females overlapped, in any mated pair the male was almost invariably larger than the female. If a pair was together, the general appearance of the two birds enabled us to determine their sex 80 to 90 per cent of the time.

Albatrosses are ideal birds to work with because of their inherent tameness. Incubating birds often allow themselves to be gently scratched

Figure 1. Stakes were driven into the ground to identify individual nests on study plots. Feathers of certain individuals were marked with dye, as illustrated on the breast of the bird at right. The edges of Laysan Albatross nests were usually built up several cm above the substratum as illustrated here. KWK 57-1A-8.

on the head (some even seem to enjoy this). Eggs are easily examined by gently nudging the incubating bird until it rises sufficiently to reveal the egg. No birds deserted their nests because of handling (except during nest-displacement experiments).

MATURITY

Age at First Return

In May and June of 1957, on Eastern Island, we marked 3,786 Laysan and 1,000 Black-footed albatross chicks with standard aluminum leg bands and red plastic leg bands; on Sand Island, 50 Laysan chicks were marked with yellow-enameled aluminum bands. In May and June 1958, on Eastern Island, 4,000 Laysan and 600 Black-foot chicks were marked with standard bands and yellow plastic bands.

During the 1957–1958 breeding season we made an intensive search for the birds color banded the previous season. Unfortunately, no one could be present to search for color-banded birds during the 1958–1959 season. Chandler S. Robbins of the U.S. Fish and Wildlife Service visited Midway in the spring of 1960, and made an intensive search for color-banded birds between 22 March and 6 April; a local cooperator, Ralph Stockstad, made

TABLE 1
SUMMARY OF RETURNS OF LAYSAN AND BLACK-FOOTED ALBATROSSES BANDED AS CHICKS

Species	*Year class*	*Number of returns*			
		1957–1958[a]	*1958–1959*[b]	*1959–1960*[c]	*1960–1961*[d]
Laysan	1956–1957	0	2[e]	22	1[f]
Black-foot	"	0	0	9	4
Laysan	1957–1958	X	0	0	2
Black-foot	"	X	0	(2)[g]	3

[a] Intensive search all season.
[b] No search made for color-banded birds.
[c] Intensive search 22 March–5 May.
[d] Intensive search 24–28 January.
[e] 7 May and 30 June.
[f] 25 May.
[g] Two Black-foots with yellow leg bands were observed, but they could not be captured.

an intensive search on 5 May. In the winter of 1960–1961, Robbins again visited Midway and searched for color-banded birds between 24 and 28 January. Their returns, plus a few others reported by other observers, are summarized in Table 1. A few additional color-banded Black-footed Albatrosses were seen in both the 1959–1960 and 1960–1961 seasons, but they evaded capture.

From these returns, it may be concluded that no appreciable segment of any year class returns to the breeding islands until the third season after hatching. Quantitative data on the age at first return may be obtained only if observations are carried on systematically throughout each succeeding breeding season after banding.

Comparison of the 1959–1960 returns with those of 1960–1961 indicates that, as in other pelagic species of birds, and in northern fur seals (*Callorhinus ursinus*), the innubile individuals tend to reach the breeding grounds relatively late in the season, the number of returns increasing as the season advances.

Age at Sexual Maturity

The only direct information on the age at which Laysan Albatrosses first nest is the record of a bird banded as a chick in 1951 and found incubating in December 1957, seven seasons after hatching. It is probable that this bird did not nest the previous season, as all nesting birds on that area were thoroughly checked repeatedly during the incubation period in 1956. It is possible, but unlikely, that it may have nested prior to 1956.

During an experimental control program by the U.S. Navy, 14 Laysan Albatrosses banded as chicks seven seasons previously were killed. All of them were apparently unemployed birds when killed. They included seven males, five females, and two of unknown sex. Only three (two males, one

TABLE 2
RELATION BETWEEN NESTING SUCCESS AND NESTING THE FOLLOWING SEASON BY LAYSAN ALBATROSSES

	Nesting, 1956–1957		*Returned, 1957–1958*	
Fate of nest	*No. of nests*	*No. of birds*[1]	*No. of birds*	*Per cent*
Egg lost early in incubation	89	167	145	87
Egg lost late in incubation	73	144	108	75
Egg sterile	75	147	128	87
Chick died during guard stage	64	126	99	79
Chick died during post-guard stage	43	86	70	81
Chick successfully fledged	75	150	94	63

[1] Number of birds does not always equal twice the number of nests, because in several instances one member of the pair was not banded the first season, or was not recaptured the second season.

female) had bare incubation patches, suggesting that they may have nested that season.

All banded birds, two to six years of age, that have returned have apparently been unemployed birds.

These data suggest that seven years is the earliest age at which Laysan Albatrosses (and probably Black-foots also) nest. This agrees closely with Richdale's (1950) data for Royal Albatrosses.

FREQUENCY OF BREEDING

To determine if Laysan Albatrosses nest in consecutive years, 497 nesting pairs were banded during the 1956–1957 season. These included 164 pairs on a control plot, and 333 pairs on experimental plots where the eggs or chicks were destroyed at different stages in the breeding cycle. Seventy-eight nests were eliminated from consideration for various reasons, leaving 419 nests for calculating the correlation between nesting success one season and nesting the following season. Of these 419 nests, on 18 only one bird could be used in the calculations, as the other pair member either was not marked the first season, or was not recaptured the second season. Thus, the results are based on 820 individual birds of known nesting success.

The results in Table 2 show that a large proportion of Laysan Albatrosses nesting in any one season, whether or not they are successful in rearing a chick, return to nest the following year. Presumably the same is true of Black-footed Albatrosses, although we have no data for that species.

The proportion of birds returning and nesting the second year varied from 87 to 63 per cent. The affinity for an established nesting site (see Territory: Maintenance) precludes the probability that birds that failed to return nested elsewhere. There may be a decreasing tendency to nest the following year with an increase in the length of the portion of the breed-

ing cycle that is successfully completed. Birds that lost their eggs early in the 1956–1957 incubation period showed the highest percentage of nesting the following season, while those that successfully fledged a chick in 1956–1957 showed the lowest percentage of nesting in 1957–1958. Additional data are required to determine if the difference is statistically significant.

ARRIVAL AT THE BREEDING GROUND

Time of Arrival

In the 1957–1958 season the first Black-footed Albatross arrived at Sand Island on 18 October, the first Laysan Albatross on 1 November. On several selected areas, counts of all albatrosses were made daily at 12:00–13:00. The results in Figure 2 show the buildup and variation in numbers from the time of first arrival until the end of the egg-laying period. Both nesting and unemployed birds were included in the counts.

On one small area the earliest arriving Laysan Albatrosses were banded. Their sexes were subsequently determined after egg laying. The first male arrived on 4 November, and five more followed on 6, 8 (2 birds), 9, and 10 November. The first female did not arrive until 10 November. This suggests that females tend to arrive a few days later than males.

Significance of the Timing of the Annual Cycle

The nesting cycles of North Pacific albatrosses begin at about the same time of year, and thus at the opposite season, as the nesting cycles of the southern hemisphere albatrosses. It is frequently stated that the North Pacific species have simply "retained" the November laying season of their presumed southern hemisphere ancestors. However, there is no evidence to indicate that an entirely endogenous annual rhythm could be maintained during the long period of time that the Laysan and Black-footed albatrosses have surely occupied their present North Pacific habitat.

Laysan and Black-footed albatrosses occupy lower latitudes, and thus a warmer climate, than do any of the southern hemisphere albatrosses. Their breeding cycle seems to be timed to ensure that the chicks are fledged prior to the period of maximum summer heat (see Development of Young: Temperature Regulation). The work of Howell and Bartholomew (1961) supports this hypothesis.

PAIRING

Formation of the Pair Bond

Formation of the pair bond in albatrosses apparently takes a considerable period of time. As stated above, birds may return to the island when three years old, but do not nest until at least seven years old. Many birds that we thought to be innubile because of their delicate build and dusky

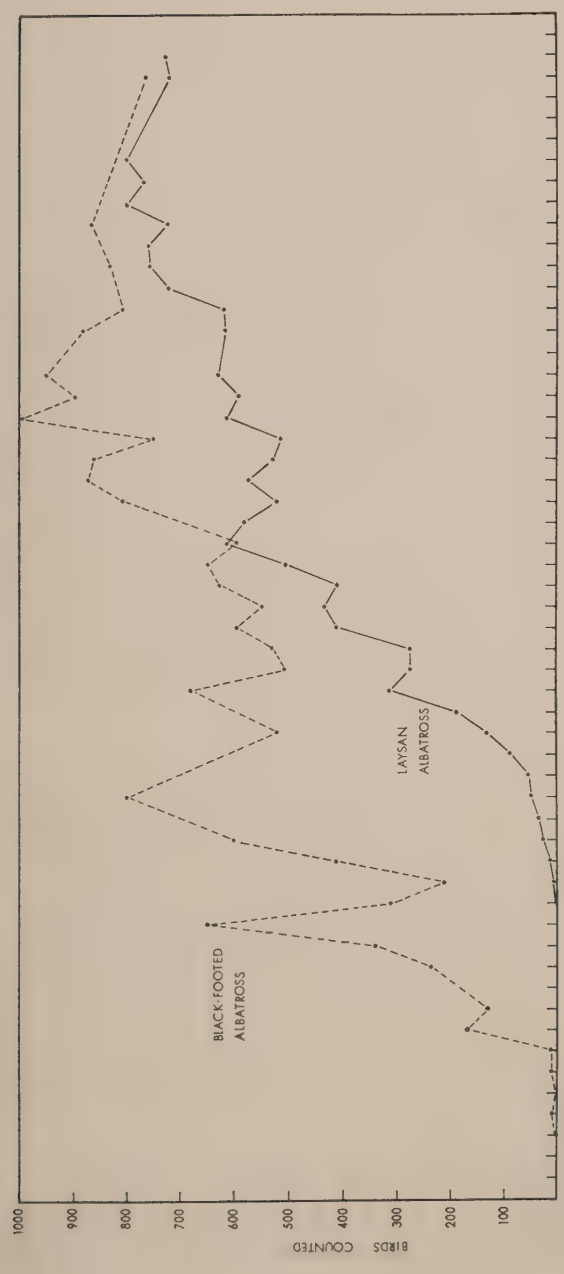

Figure 2. Daily counts of Laysan and Black-footed albatrosses on sample plots at Midway Atoll from time of arrival until the end of the egg-laying period.

TABLE 3
MAINTENANCE OF PAIR BOND FOR TWO SEASONS IN 341 MARKED PAIRS OF LAYSAN ALBATROSSES

Status of pairs	*Number*	*Per cent*
Pairs returned intact	323	94.7
Pairs returned divorced (both birds with new mates)	7	2.1
Only one member returned (with new mate)	11	3.2

feathers on their thighs were found "keeping company," dancing, and sometimes building nests, but not breeding.

On one experimental study plot, the mates of 76 incubating birds were killed. The following season only 10 (13 per cent) had acquired new mates and nested. At least 29 of the remaining 66 birds returned as unemployed birds to the same area. This indicates that a year or more may be required to consummate a pair bond after loss of a mate.

In one unusual case a male whose mate's egg was destroyed was discovered a few days later on another nest incubating an egg newly laid by another female. He and the new female incubated and hatched this egg.

Duration of the Pair Bond

The pair bond normally remains intact until broken by the death or disappearance of one of the partners; divorces are very rare. On several study plots, 341 marked pairs of Laysan Albatrosses were followed through two nesting seasons (1956–1957 and 1957–1958). The status of the pairs during the second season is shown in Table 3.

DISPLAYS AND VOCALIZATIONS

The principal ritualized display postures are described below. The terminology of Richdale (1949, 1950) has been retained insofar as it was possible to determine homologies from his descriptions and photographs (Richdale's terms are marked with an asterisk in the following account). We found several display postures that have not been previously described for other species of albatrosses: Whinnying, Head-up-and-whine, Head-up-and-clap, and possibly Bowing. We did not observe the following postures in the Laysan and Black-footed albatrosses: Wing-stretching, Wailing, Gulping, Bill-clashing, Tattooing; nor did we observe any aerial activity connected with social relationships. If any of these postures are present in Laysans and Black-foots, they have been so modified that their homologies are not obvious.

Vocalizations

Homologous calls are used by Laysan and Black-footed albatrosses. The calls of the Black-foot have a decided nasal quality and are louder, lower

pitched, and hoarser than those of the Laysan. The primary calls of the adult are the following:

Whinny. This is a wavering wail greatly resembling the whinny of a horse. It is frequently used by Laysans, rarely by Black-foots.

Whine. This is a smooth, long drawn-out scream: *Wheeeeee* in the Laysan, *Haaaaaw* in the Black-foot. It is given with the Head-shake-and-whine and the Head-up-and-whine posture. A similar sound is uttered when a bird is grabbed by a wing tip and prevented from escaping.

Moo. This is a cowlike moo uttered only from the Sky-call posture (Figure 3).

Double-call. This is a high-pitched *eh-eh* in the Laysan, and a donkey-like braying *haw-haw* in the Black-foot. It is uttered chiefly from the Yapping posture.

Yammer. This is a rapidly repeated series of snorting honks habitually given by the Black-foot during aggressive displays, rarely by Laysans.

Displays

All of the display postures described are used by both Laysan and Black-foots. The Black-foot, unlike the Laysan, often keeps its wings slightly fanned while performing the various displays. Minor variations between the two species are noted below.

Bowing. Bowing may be homologous to the Scooping action of Buller's Albatross (Richdale, 1949). It differs in that the tail is not spread. Bowing is performed by bobbing the head, neck, and foreparts up and down.

*Gawky-look.** This distinctive stance, with the head forward, is often assumed by one bird while watching its partner performing, and is assumed in the intervals between other postures in the dance. It also precedes Billing (cf. Frontispiece).

*Billing.** Richdale (1949) also calls this the Rapier action in reference to the Buller's Albatross. It begins with the Gawky-look. The bird then extends its head and bill forward and gently touches the bill of the partner with the tip of its bill. This may be followed by the two birds gently nibbling each other's bills. We were often able to elicit this reaction by pointing a finger toward a bird. The bird would then gently nibble the tip of our finger.

*Mouthing.** This could better be called mutual preening, but we retain Richdale's (1950) term. It is usually performed from the sitting position by mated pairs or birds keeping company. One bird gently nibbles the other on the head, particularly on the cheeks and chin. The partner tilts and turns its head to expose better the parts being nibbled. Often we were able quietly to approach a sleeping bird and simulate Mouthing

Figure 3. Laysan Albatross showing the Sky-call posture and uttering the Moo. KWK 994.

by gently scratching the bird on the cheek. This would elicit the head turning and tilting, which would continue until the bird opened its eyes.

*Yapping.** Yapping usually is performed from a crouching position. The neck is drawn in; the bill is pointed straight down, or inclined back toward the feet. The Double-call is repeatedly uttered. In the Laysan and Black-footed albatrosses, Yapping differs from the Yapping of Royal Albatrosses (Richdale, 1950) and the Croaking and nodding of Buller's

Figure 4. Yapping is illustrated by the albatross immediately after being disturbed during incubation. Birds always exhibited Yapping behavior when returning to the nest, and often at other times. KWK 57-6-0.

Albatross (Richdale, 1949); however, when its relationship to the birds' activities is considered, their homology seems reasonably certain. Yapping occurs chiefly between pairs keeping company; between mated pairs on their breeding territory, whether nesting or not; and between a bird and its egg or chick (Figure 4).

*Snapping.** From either the sitting or the standing positions, Snapping is performed by sharply closing the bill a few times. It may be performed alone, or in the presence of another bird. Occasionally it is performed in flight. A more intense variation of Snapping is used as threat display toward men, dogs, and other albatrosses; in Black-footed Albatrosses it is often accompanied by the Yammering call.

*Clappering.** The bill is repeatedly opened and closed so rapidly that the lower mandible is blurred. This makes a sound similar to the drumming

Figure 5. Black-footed Albatrosses exhibiting the Clappering position during the dance ceremony. In the Laysan Albatross the birds face each other in the Clappering position. KWK 57-4-17.

of a woodpecker. When Clappering, Laysan Albatrosses face each other and pull their heads and necks back and hold their bills at a downward angle, nearly parallel to the necks. Black-footed Albatrosses hold their heads side by side, arch their necks forward, and hold the bills downward (Figure 5).

Whinnying. Richdale (1950) confused Hadden's (1941) description of Whinnying in the Laysan Albatross with the Head-shake-and-whine. Whinnying has not been reported in other species of albatrosses. It is used frequently by the Laysan, rarely by the Black-foot. It is performed from the same position as Clappering, and is accompanied by the Whinny call, uttered with the bill nearly closed.

*Head-shake-and-whine.** Head shaking is done from the same stance as Clappering and Whinnying. The head rapidly swings from side to side several times with the beak open, while the Whine is uttered. It is given infrequently.

*Sky-call.** When Sky-calling, the birds rise on the tips of their toes, stretch their necks and point their bills upward. From this position the Moo call is given once with the bill very slightly open (Figure 6). The Sky-call is used frequently in the dance. Single birds may exhibit a less

Figure 6. Laysan Albatrosses displaying the Sky-call position. DWR 997.

intense version, in which they may not raise their heads so high, nor stand up on their toes (Figure 3). We have also seen it performed at sea by Black-foots resting on the water. It is never used to call to a bird flying overhead.

Head-up-and-whine. This is given from the same posture as the Sky-call, but the bill is widely opened and the Whine is uttered (Figure 7). It is sometimes given by a bird immediately after it has chased away another bird, and is also given during the dance.

*Scapular-action.** In this posture, the tip of the bill is placed near the bend of the wing and the bill is lightly clappered for one or two seconds. Black-foots fan both wings forward (keeping them partially folded) during this display, but Laysans fan only the wing on the side on which the action is performed (Figures 8 and 9).

Head-up-and-clap. This posture has not been described for other species of albatrosses. It invariably follows the Scapular-action, and is not given at other times. The bird assumes the same posture as for the Sky-call, but snaps the bill once, instead of Mooing. The Head-up-and-clap may be homologous to the Wail of Buller's Albatross (Richdale, 1949), as both usually follow the Scapular-action.

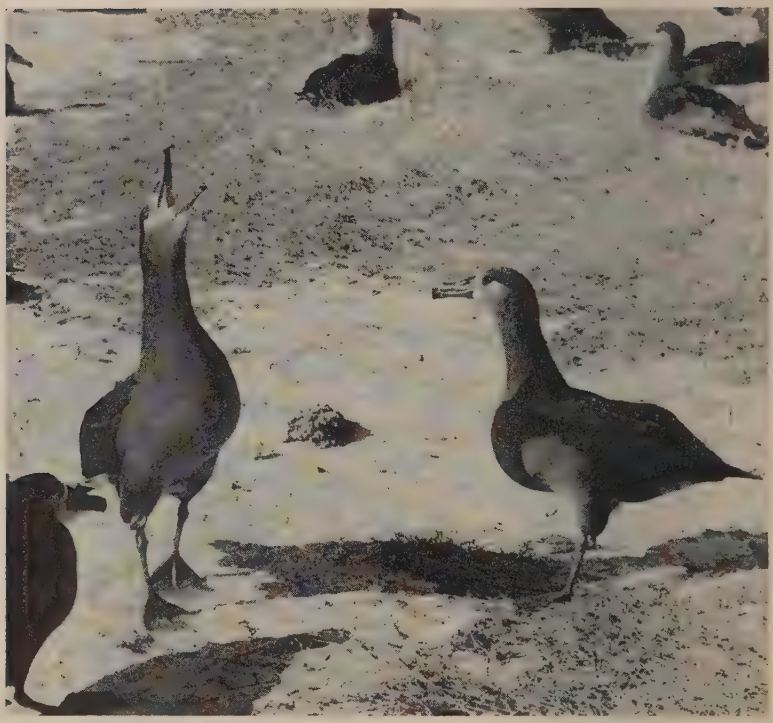

Figure 7. The Black-footed Albatross on the left demonstrates the Head-up-and-whine posture while its dancing partner on the right approaches the Gawky-look. Note that the incubating birds in the background have not built up the edges of their nests to the extent usually done by the Laysan Albatross. KWK 57-4-14.

The Dance

Richdale (1950) terms the dance the "Ecstatic Ritual." The dance is a mutual gamosematic and/or epigamic display. On 6 February 1958 we killed six dancing pairs, and one dancing trio, of Laysan Albatrosses, all apparently unemployed birds. Autopsy revealed that each pair consisted of a male and a female; the trio included one male and two females. Dancing begins with the arrival of the birds on the breeding ground and is discontinued only by mated pairs after nest building has begun. Unemployed birds continue to dance during the entire breeding season, but the frequency of dancing is reduced as the season advances.

In many respects, the dances of the Laysan and Black-footed albatrosses are similar. The differences, however, are apparent to even the casual observer, and are such that birds of the two species, although they may

Figure 8. During Scapular-action the Black-footed Albatross fans both wings. KWK 57-4-19.

Figure 9. During Scapular-action the Laysan Albatross fans only one wing. DWR 996.

start to dance together, invariably discontinue the affair with shrieks and an attack by one on the other.

A dance begins when two birds face each other, assume the Gawky-look posture, and engage in Billing and Bowing. The displays and vocalizations (as detailed previously) follow in varying sequence. The most frequent displays are Clappering, Whinnying, and Scapular-action, usually terminating with the Head-up-and-clap. The Head-shake-and-whine, Sky-call, and Head-up-and-whine are also performed during the dance. Clappering is usually performed in unison by the two birds, but the other displays are not necessarily synchronized. The most apparent differences in the dances of the two species are in the so-called Scapular-action (Figures 8 and 9), and in Clappering. All actions, however, differ in degree, and a detailed study would reveal rather noteworthy quantitative differences in all analogous rituals of the two species.

TERRITORY

Breeding territory of albatrosses may be classified as Type C of Hinde (1956). It is confined to the immediate vicinity of the nest, and is used only for mating and nesting. In densely occupied areas, nests are far enough apart only to permit a bird (or man) to walk between them without being pecked by setting birds on either side.

Establishment

No albatrosses banded as chicks have been found nesting in subsequent years at the site where they were hatched. On the other hand, two Laysan Albatrosses have been found nesting at some distance from their hatching sites. One hatched on Sand Island in 1937 was found nesting 500 meters away, on the same island, in 1957–1958. Another hatched on Eastern Island in 1951 was found nesting on Sand Island, five km away, in 1957–1958. Of 45 two-, three-, and four-year-old birds recaptured (see Age at First Return), 44 were on the island on which they were hatched (24 Laysans and 18 Black-foots on Eastern Island; 2 Laysans on Sand Island), mostly not far from their hatching sites; one Laysan Albatross hatched on Eastern Island was found dead on Sand Island two seasons later. Of 97 banded Laysans that hatched on Eastern Island in 1951, 14 were killed on Sand Island in 1958, seven seasons later, during a control program on that island; these were apparently mostly unemployed birds (see Age at Sexual Maturity). These records indicate that innubile birds wander and eventually establish territories some distance from their hatching sites.

Apparently very few settle down on other atolls, however. Thousands of albatrosses have been banded on Midway, but, despite diligent search,

TABLE 4
DISTANCE BETWEEN NESTING SITES IN THE 1956–1957 AND 1957–1958 SEASONS, OF 101 MARKED PAIRS OF LAYSAN ALBATROSSES

Distance moved (meters)	*Number of pairs*	*Per cent*
0–1	44	43.5
1–2	34	33.7
2–3	11	10.9
3–4	7	6.9
4–5	3	3.0
5–6	2	2.0
6+	0	0

none of these have been found on Laysan Island, and only one Black-footed Albatross was found at Kure Atoll.

General observations suggest that territory is initially established during the pair-formation period. Many pairs "keeping company" but not nesting show a strong attachment for a particular site, and may even build play nests.

Maintenance

Adult albatrosses, once they have established a breeding territory, return to it season after season. No marked albatross has ever been found nesting at widely separated sites in different years. Many birds banded as adults in 1938 on Sand Island at the site of Gooneyville Lodge (the old Pan-American Airways hotel, destroyed in 1957) were still nesting there during the 1956–1957 and 1957–1958 seasons; none have been found nesting elsewhere.

During the 1956–1957 season, the locations of the nests of 166 marked pairs of Laysan Albatrosses were plotted on a large-scale map. The following year, 1957–1958, 101 of these pairs returned intact and nested. The locations of their nests were again mapped. The two seasons' maps were compared, and the distances the birds moved their nest sites between subsequent seasons were measured. Over 50 per cent of all pairs constructed their nests within 1.3 meters of the previous year's site; none moved farther than six meters (Table 4). In general, those nesting adjacent to an obvious landmark, such as a tree or bush, showed less deviation than those that nested in the middle of a large, open area.

During the nesting season, the adult albatross maintains such a strong affinity for its exact nest site that it will not feed its chick until the latter returns to within a few meters of the nest site (see Parental Care: Recognition between Parents and Young).

Experiments in Displacement of Nests and Chicks

The proposition has been presented that as an aid to reducing the bird

TABLE 5
RESULTS OF EXPERIMENTAL NEST DISPLACEMENT 5 FEBRUARY 1957

Nest No.	*Nest contents*	*Distance moved (meters)*	*Results*[1]		
			5 February	*8 February*	*11 February*
1	Pipped egg	1.0	Move accepted	Move accepted	Move accepted
2	Newly hatched chick	1.5	Move accepted	Move accepted	Move accepted
3	Newly hatched chick	2.0	Not accepted; parent flew off	Chick dead; parent at old nest site	Adults at original nest site
4	Pipped egg	2.0	Move accepted	Chick dead; parent on nest	Adults at original nest site
5	Newly hatched chick	2.0	Move accepted	Chick dead; parents gone	Adults at original nest site

[1] On 14 February area was bulldozed.

populations on Sand Island, Midway Atoll, albatrosses (adults and chicks) might be moved to other islands where they would not interfere with human activities.

Although general observation of albatrosses and ethological studies of other species would indicate that nesting albatrosses could not be successfully displaced any significant distance from their original nest sites, the following experiments were conducted to determine whether or not the Laysan Albatross would accept its nest (and egg or young) after it had been displaced from the original nest site.

On 5 February 1957 the nests and eggs or chicks of five pairs of Laysan Albatrosses were carefully slipped onto a sheet of plywood, and displaced one to two meters from their original sites. Immediately after being moved, three of the adult birds returned to the original nest site (Table 5), although all signs of the nest had been removed and the spot where the nest had been was made to look like its surroundings. The birds were then picked up and replaced on the nest in its new location. Two individuals had to be replaced on their nests two or three times in a period of about 15 minutes, and one parent, becoming quite upset, fled from the area. Four birds, however, appeared to have accepted the new nest position an hour after the displacement. The parent that fled returned to the original nest site, but not to its chick at the new site two meters away. The newly hatched chick died of exposure during the night. Two of the new nest sites, moved respectively 1.0 and 1.5 meters, were ultimately accepted. The fourth and fifth nests, which had been displaced 2.0 meters, appeared for nearly two days to have been accepted. However, the adults then returned to the old nest sites, and by 8 February both chicks were dead. The adults belonging to the three nests that had been moved two meters, and whose chicks had died, were seen at the original nest sites until 14

February, when the study area was unexpectedly bulldozed for building construction.

On 8 February 10 nests containing young, one to two weeks old, were moved distances of 1.0, 2.0, 3.0, 3.5, and 4.0 meters. With one exception the parent present at each nest when it was moved was induced to accept the nest in its new location. The parents occupying nests moved more than two meters had to be induced repeatedly to leave the original nest sites and return to the nest in its new position. On 14 February building construction on the area terminated the experiment so that it was impossible to ascertain the ultimate results of nest displacement.

The questions left unanswered in the experiments are: (1) Would the parent that was originally forced to accept the nest displacement return and feed its chick at the displacement site after going to sea? (2) Would the adult that was at sea when the nest was moved return to the old nest site, and fail to feed its chick at the displacement site?

In addition to the above displacement experiments, we made observations on two instances of accidental displacement:

On 14 February 1957 construction crews began work on a new building. Before bulldozing the area, the crews removed all young and parent albatrosses from the working area. We were not present when this was done, but a crew member told us that when possible parents and young were moved together, and he showed us where they had been placed, at distances of 20 to 100 meters from the original nest sites. Approximately 100 young were displaced; we marked 25 with red dye. The displaced chicks were immediately deserted by their parents. Within a few hours each chick had constructed a new nest. The parents continued to ignore them and returned as nearly as possible to the original nest sites. During the day when construction was in progress they rested outside the construction zone, but each day after working hours they returned to spend the night at or near the old nest sites. At intervals of two to three days during the following weeks we visited the displaced young. Although adults often wandered about near them, none was seen feeding a young bird. The young were not weighed, but it soon became apparent that they were starving. Several of the youngest died in early March. Four died on 17 March and six on 21 March, the remaining 10 to 15 within the next week. The last, nearly dead, was observed on 27 March. Death from starvation thus ranged from about 20 to 42 days.

On 9 March 1957 a *tsunami* washed many five- to six-week-old young Laysan Albatrosses from their nests and deposited them 20 to 50 meters away. A few of the larger individuals returned to their original nest sites, where they were successfully reared. Four individuals that remained where the wave had deposited them, near the bases of trees along a route we often

took, were observed almost daily until they died, two on 10 April and the other two on 14 April, 32 and 36 days respectively after displacement.

From these experiments and observations we conclude that helpless young albatrosses (newly hatched to 10 days old) may be displaced approximately one meter from the original nest site with only moderate danger of desertion or neglect by parents, if parents are moved with the young. If helpless young are moved greater distances, they will usually not be recognized by their parents and will ultimately starve.

Well-fed young, displaced 50 or more meters from their original nest sites at the age of three to six weeks, are usually unable to find their way back to the original nest site, and remain at the new location. They are not recognized or fed by their parents, which continue to frequent the original nest site. All young thus observed died of starvation in approximately a month to six weeks.

Because they survive for a long period without food after being displaced, casual observers at Midway believed that displacements were successful; they failed to associate the eventual death of the young with displacement from the nest site, which took place weeks earlier. Older chicks, which are able to return to the nest site, will survive when displaced for moderate distances if they are not physically prevented from returning to the nest site to be fed. Displaced chicks that cannot return to the original nest site stand a poor chance of successful fledging.

Defense

Albatrosses do not vigorously defend their breeding territories. They will attack an intruder that gets in their way, but they will not leave the nest while they are incubating or brooding. At this time, defense consists only of snapping at or pecking other birds or human intruders that come close to them.

In general, albatrosses get along well with their established neighbors. Defense is directed largely toward unestablished birds that are seeking territories, and mainly serves to establish a minimum distance between nests.

A ritualized display, the Head-up-and-whine, often follows the expulsion of an intruder.

NEST BUILDING

Both sexes participate in the construction of the nest. Nest building begins only one to three days before the egg is laid.

The nests of both species are of the directly adaptive type, consisting primarily of a depression in the sand or humus, with the rim built up to a variable extent. The nest is formed by scraping the material of the substratum backward with the feet. The body is rotated in the depression,

forming it to the shape of the bird, and producing a raised, craterlike edge. The Laysan Albatross, to a greater degree than the Black-foot, uses the bill to rake sand, twigs, and leaves to the rim of the nest; this material is pressed down and compacted with the side of the bill. Material is gathered only while the bird is sitting on the nest. As a result, a ring-shaped moat up to five cm deep often encircles the nest. The hard rim of the nest may project 15 cm above the surrounding surface. The outside diameter of a nest (including moat) is about one meter. The nests of Black-foots are much less built up than those of the Laysan, probably because of the nature of the substratum. In areas of loose sand, most frequently used by Black-foots, nests are little more than scooped-out hollows in the sand.

Albatrosses continue to improve their nests throughout the incubation period and guard stage. Heavy rains always initiate a flurry of nest-building activity by incubating birds, perhaps because the substratum is easier to work when wet.

Newly hatched chicks, particularly the Black-foots, begin kicking sand out of the nest immediately after hatching (Figure 10). The instinctive kicking of sand from the nest by this predominantly open-beach nesting species has survival value during wind storms; if a storm is prolonged, young birds which become exhausted are buried alive.

During the guard stage when chicks become too large to be comfortably brooded, they frequently leave the nest and build a miniature nest of their own, adjacent to and confluent with the original nest on which the parent is sitting.

During the post-guard stage, chicks often build one or more additional nests within 30 meters of the original nest. If the original nest is exposed to sunlight, they may build a nest in the shade for use during the day, and return to the original nest at night. Chick nests never reach the proportions of the better-constructed adult nests.

Nests are often built by nonbreeding pairs, or birds "keeping company."

EGG LAYING

Length of Pre-egg Stage

The interval between the arrival of the first birds and the laying of the first eggs, and the interval between the date when approximately 50 per cent of the birds have arrived and the modal date for egg laying, is 14 to 16 days for the Laysan Albatross, and 18 to 21 days for the Black-footed Albatross.

The length of the pre-egg stage for seven individual Laysan Albatrosses was determined. For six males it varied from 13 to 21 days, with a mean of 16.5. For the one female it was 12 days. A shorter pre-egg stage is indi-

Figure 10. Almost from the moment of hatching, young albatrosses use their feet to kick sand from the nest. This is a survival factor, particularly during wind storms, and is exhibited to a greater extent by the predominantly beach-nesting Black-foots than by the Laysans. DWR 1003.

cated for females, because they tend to arrive on the breeding grounds later than the males.

Clutch Size

Laysan and Black-footed albatrosses lay only one egg per year. Very rarely we found a second egg outside a nest, or even in a nest, but it usually differed in size, shape, and markings from the one in the nest, indicating that it had been dropped by another bird (human interference was responsible for many of the observed cases of two eggs at one nest).

On one study plot the eggs of 95 marked pairs of Laysan Albatrosses were destroyed early in the incubation period. In only two cases did apparent relaying take place. One egg was destroyed on 30 November while the male was incubating; on 2 December a new female was found on the nest, incubating a new egg, with the male beside her. The female that laid the original egg was not in the vicinity. At another nest the egg was

destroyed on 3 December while the male was incubating; on 7 December he was found incubating a new egg. Unfortunately, this egg was accidentally broken, so we were unable to determine which female laid it.

In another experiment the eggs of 70 marked pairs of Laysans were destroyed late in the incubation period. In no instance was a second egg found in any of their nests.

Factors Controlling Clutch Size

To determine if a pair of albatrosses can hatch more than one egg, we gave second eggs to a number of birds at various times during the incubation period. The bird's incubation patch can accommodate only a single egg. Setting birds appear very "uncomfortable" with two eggs, and usually push the second egg out. If it remains in the nest, it does not receive enough heat to develop. Sometimes it will be partially buried in the floor of the nest. In no case did two eggs hatch. In a few instances the presence of two eggs resulted in neither hatching, apparently because alternate incubation of each egg was insufficient to permit them to develop. It is obvious that albatrosses are unable to incubate two eggs.

To determine if a pair of albatrosses can raise two chicks simultaneously, 18 pairs of Laysans were each given a chick in addition to their own. This was done on 11 February when the chicks averaged nine days old. At this early age adult albatrosses will readily accept foster chicks if their own is lost. The chicks were examined at three- to four-day intervals until 21 May.

In at least nine nests both chicks were subsequently fed by the parents. In most cases one chick grew faster than the other. As the chicks grew older, they became increasingly aggressive toward each other, and one usually drove the other several meters away from the nest. On two observed feedings the larger and more aggressive chick received all the food from the parent.

At 15 nests both chicks died. At one nest a single chick survived. At two nests both young survived but one set was so emaciated that their survival to fledging was improbable. Thus out of 18 nests containing a total of 36 chicks, possibly three chicks were fledged. On the average, 18 normal nests (containing one chick each) would fledge about 12 or more chicks. It appears that a clutch of one is the optimum that produces the highest number of fledged chicks per nesting pair.

To determine if a single parent can successfully raise a chick, one member of each of 16 marked pairs of Laysan Albatrosses was killed on 11 and 14 February. The presumed average age of their chicks was 9 to 12 days, and all were at least three days old. The chicks were examined at three- to four-day intervals until 25 July. Three of the chicks were accidentally

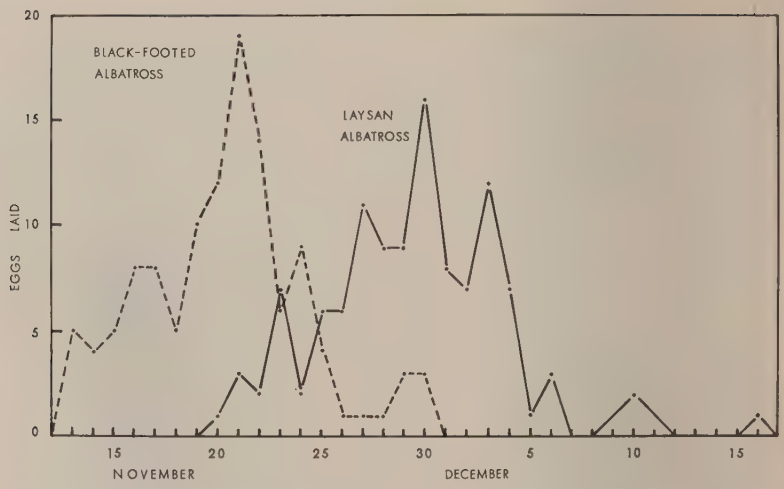

Figure 11. Egg-laying dates of 115 Laysan and 118 Black-footed albatrosses at Midway Atoll in 1957.

killed. Of the remaining 13, only one was fed regularly; the other 12, as evidenced by their frequently empty stomachs and retarded growth, were fed less frequently than normal chicks. Five chicks died of apparent starvation on 21 February, 23 and 28 March, 6 April, and 25 July. Only eight chicks survived. The one that appeared to have been fed regularly was last seen on 2 July and presumably fledged successfully. The other seven were still present on 25 July, well after the normal departure date; one of these was so emaciated that its early death was certain. It thus appears that a single adult is seldom able to supply a chick with sufficient nourishment for normal growth throughout the nestling period.

Time of Egg Laying

Egg laying averages about 10 days earlier in the Black-footed Albatross than in the Laysan Albatross.

In the 1957–1958 season we found the first Black-foot egg on 8 November. On one study plot where 118 nests were under daily observation, laying extended over a period of 18 days, from 13 to 30 November (Figure 11). The mean time of egg laying was 21:00 on 21 November (SE = 11 hr), with a standard deviation of 5.11 days. The median date was 20 November, the mode 21 November.

The first Laysan Albatross egg was found on 15 November. On a study plot where 115 nests were under twice-daily observation, laying extended over 27 days, from 20 November to 16 December (Figure 11). The mean

time of egg laying was 07:00 on 30 November (SE = 12 hr) with a standard deviation of 5.21 days. The mode and median date was 30 November.

Eggs are laid at any time of day. At 115 Laysan nests egg laying occurred during the 14 hours from dusk until dawn 50 times, and during the 10 daylight hours 65 times. At 10 Black-foot nests five eggs were laid at night, five during daylight.

Behavior of Female during Egg Laying

The act of egg laying by Laysan Albatrosses was observed three times—twice briefly, once in detail. In each instance the bird was standing over the nest at the moment the egg was dropped. Field notes on the one complete observation, made at a distance of less than two meters, starting at 17:03 on 4 December 1957, follow:

17:03—Female standing on nest; wings drooping. Cloaca alternately dilating and closing, so that the egg was visible in the cloaca when the latter was dilated. The interval between successive dilations was about seven seconds at first, later slowing to 10 and 11 seconds.

17:10—Cloaca open about 30 mm; egg continuously visible.

17:12:00—Female (still standing) leans back, raising breast, and lowering posterior end of body almost to surface of nest.

17:12:20—Egg drops. Female resumes previous normal standing position, bends head down, and looks at egg. Silent; does not touch egg with beak.

17:12:50—Female settles on egg and begins incubation.

The male was not present when this egg was laid. The female remained on the egg until the next day, when the male arrived. The male took over incubation sometime between 08:00 and 18:00 on 5 December.

INCUBATION

Length of Incubation Period

Ninety-five Laysan Albatross nests were observed twice daily from before egg laying until after hatching. The incubation period varied from 62.5 to 68.0 days (Table 6). The mean was 64.44 days (SD = 1.02; SE = 0.10). The mode was 64.0 days, the median 64.5 days.

Seventy-five nests of Black-footed Albatrosses were observed once daily beginning prior to egg laying and continuing until egg laying was completed, and again from prior to hatching until hatching was completed. The incubation period varied from 63 days to 68 days (Table 7). The mean was 65.57 days (SD = 1.18; SE = 0.14). The mode and median was 65 days.

The difference in the mean length of the incubation period of the two species is highly significant statistically ($P < 0.001$).

TABLE 6
LENGTH OF INCUBATION PERIOD OF 95 LAYSAN ALBATROSS EGGS

Number of days	*Number of eggs*	*Per cent*
62.5	4	4.2
63.0	3	3.2
63.5	14	14.7
64.0	23	24.2
64.5	22	23.1
65.0	14	14.7
65.5	6	6.3
66.0	2	2.1
66.5	5	5.3
67.0	0	
67.5	1	1.1
68.0	1	1.1

Participation of the Sexes

Both male and female albatrosses share in incubation. While one bird is setting, its mate remains at sea. The egg is incubated continually from laying until hatching and is never left unattended, even briefly, either during an incubation span or during nest relief. On 110 Laysan Albatross nests under regular twice-daily observation for a total of 7,319.0 nest days, the male was incubating 4,099.0 (56 per cent) days, the female 3,220.0 (44 per cent) days. On 35 Black-foot nests under observation for 1,925.5 nest days, the male was incubating 1,026.5 (53 per cent) days, the female 899.0 (47 per cent) days. The lesser amount of time spent incubating by the female is due primarily to the shortness of her first incubation span or shift.

Both sexes develop an incubation patch. In non-nesting birds it is partially or completely covered with short, gray down. The down is shed before the start of incubation, leaving an oval, slightly concave, bare area just large enough to accommodate the single egg.

Foreign objects such as rocks, coffee cups, and beer cans are readily accepted in lieu of the egg, and are incubated for the full term, even if the egg is in sight near the nest.

TABLE 7
LENGTH OF INCUBATION PERIOD OF 75 BLACK-FOOTED ALBATROSS EGGS

Number of days	*Number of eggs*	*Per cent*
63	1	1.3
64	13	17.3
65	25	33.3
66	20	26.7
67	10	13.3
68	6	8.0

TABLE 8
LENGTH OF INCUBATION SPANS OF LAYSAN ALBATROSSES

Span number	*Sex*	*N*	*Number of days*			
			M	*SD*	*95% confidence interval*	*Range*
1	♀	110	2.53	3.59	1.85– 3.21	<0.5–17.0
2	♂	110	22.58	4.41	21.74–23.41	1.5–32.0
3	♀	110	21.69	4.11	20.91–22.47	13.5–38.0
4	♂	101	14.80	3.63	14.09–15.52	6.0–23.5
5	♀	75	7.32	2.86	6.66– 7.98	2.5–18.0
6	♂	17	7.09	2.48	5.82– 8.36	4.0–12.5
7	♀	2	5.50			4.0– 7.0
Last[1]	♂ or ♀	95	8.32	4.23	7.45– 9.18	2.5–26.5

[1] Span during which egg hatched, regardless of number (includes, in part, spans 3 to 7).

When an albatross returns to relieve its mate at incubation, the setting bird is reluctant to leave the nest. The pair may remain together at the nest for several hours, indulging in Mouthing and giving the Double-call. Finally, the newly arrived bird manages to displace its mate from the nest. Once displaced, the previously incubating bird does not attempt to get back on the nest; it shortly leaves and heads out to sea.

Of 385 recorded changeovers of Laysan Albatrosses, 108 (28 per cent) took place during the 14 hours from dusk until dawn, 277 (72 per cent) during the 10 hours of full daylight. Of 165 changeovers by Black-foots, 61 (37 per cent) took place at night, 103 (63 per cent) during daylight. Most of the changeovers recorded as having occurred during the night probably took place between 18:00 and darkness, or between dawn and 08:00. During the hours of darkness, albatrosses are seldom seen in flight over land and are generally inactive.

Incubation Spans

Incubation spans by individual birds are prolonged. Laysan Albatrosses incubate for significantly longer spans than do Black-foots. Statistical data on the length of the incubation spans of 110 pairs of Laysans and 33 pairs of Black-foots are presented in Tables 8 and 9, and are shown graphically in Figure 12. The length of incubation spans is determined, of course, not by the setting bird, but by the length of time its mate remains at sea.

The females of both species remain on the egg for only a short period after laying. The female is normally relieved by the male within three or four days.

The second span (the first by the male) is much longer than the first, and is usually the longest span of the entire incubation period. In the Laysan Albatross, it averages 22.58 days, and may last as long as 32.0 days. In the Black-foot, the second span averages 18.16 days, with a maximum of 34.0 days.

TABLE 9
LENGTH OF INCUBATION SPANS OF BLACK-FOOTED ALBATROSSES

Span number	*Sex*	*N*	*Number of days*			
			M	*SD*	*95% confidence interval*	*Range*
1	♀	12	3.62	3.92	1.16– 6.09	<0.5–11.5
2	♂	19	18.16	7.24	14.69–21.69	8.0–34.0
3	♀	33	15.77	4.41	14.21–17.33	7.0–23.0
4	♂	31	17.02	6.04	14.80–19.23	7.0–39.0
5	♀	30	9.95	3.83	8.52–11.38	3.0–17.5
6	♂	16	8.84	3.91	6.77–10.91	3.5–18.0
7	♀	7	4.50			0.5– 9.5
8	♂	4	2.50			1.5– 5.0
9	♀	1	2.00			
10	♂	1	1.00			
11	♀	1	3.50			
12	♂	1	1.50			
Last[1]	♂ or ♀	26	7.15	4.25	5.44– 8.87	1.5–14.5

[1] Span during which egg hatched, regardless of number (includes, in part, spans 5 to 8, and 12).

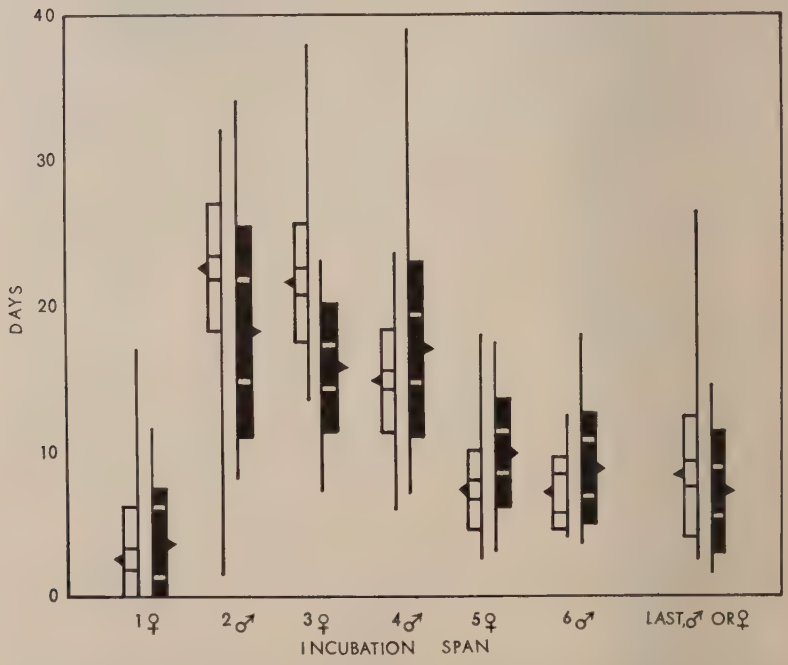

Figure 12. Length of incubation spans of Laysan Albatrosses (white bars) and Black-footed Albatrosses (black bars). Vertical line indicates the range; triangle, the mean; vertical bar, one standard deviation above and below the mean; crosslines inside bar, the 95 per cent confidence interval.

TABLE 10
SPAN DURING WHICH HATCHING OCCURRED AT 94 LAYSAN ALBATROSS NESTS AND 26 BLACK-FOOTED ALBATROSS NESTS

Number of spans	*Laysan Albatross*		*Black-footed Albatross*	
	No.	*Per cent*	*No.*	*Per cent*
3	1	1.0		
4	22	23.4		
5	54	57.4	11	42.3
6	15	16.0	8	30.8
7	2	2.1	3	11.5
8			3	11.5
9				
10				
11				
12			1	3.8

In the Laysan Albatross the third span (the second by the female) is only slightly shorter than the second. The fourth span (the male's second) is significantly shortened to a mean of 14.80 days. The fifth and subsequent spans are further shortened to a mean of less than eight days. In the Black-footed Albatross the third and fourth spans are only slightly shorter than the second. There is a marked reduction to a mean of 9.95 days during the fifth span, and each succeeding span is progressively shorter.

At 94 Laysan Albatross nests the egg hatched during the third to the seventh span (Table 10); the majority hatched during the fifth span (M = 4.95; SD = 0.725; SE = 0.075). At 26 Black-foot nests the egg hatched during the fifth to the eighth spans, except for one that hatched during the twelfth (Table 10); the mode was the fifth span (M = 6.15; SD = 1.567; SE = 0.308).

The mean length of the span during which hatching occurred (regardless of number) was 8.32 days in the Laysan, 7.15 days in the Black-foots (Tables 8 and 9).

The longest normal (relieved) spans recorded during this study were 38.0 days in the Laysan Albatross, 39.0 days in the Black-foot. Incubating albatrosses that are not relieved, due to desertion by or death of their mates, remain on their nests longer than normal. Maximum spans were 42.0 and 52.0 days by two female Laysans, and 41.5 and 49.0 days by two female Black-foots.

Incubating birds lose considerable weight during the long incubation spans; no food is ingested while they are incubating, and they drink only a few drops of rain, which they avidly attempt to catch with open upstretched beak. We weighed 17 incubating Laysans at four- to six-day intervals over four- to 23-day incubation spans. In Table 11 the initial and final weights of these birds are presented. Weight loss may exceed 20 per

TABLE 11
WEIGHT LOSS OF LAYSAN ALBATROSSES DURING INCUBATION[1]

Number days incubating	*Weight (kg)*		*Loss*	
	At start	*At end*	*kg*	*Per cent*
4	3.12	3.01	0.11	3.5
5	2.38	2.32	0.06	2.5
5	2.55	2.44	0.11	4.3
6	3.29	3.12	0.17	5.2
9	2.61	2.44	0.17	6.5
9	3.06	2.78	0.28	9.1
10	3.46	2.87	0.59	17.1
11	3.69	3.17	0.52	14.1
11	2.78	2.61	0.17	6.1
11	2.61	2.38	0.23	8.8
11	2.83	2.44	0.39	13.8
11	2.89	2.66	0.23	7.9
12	3.69	3.29	0.40	10.8
16	3.35	2.61	0.74	22.1
16	3.23	2.66	0.57	17.6
17	2.78	2.32	0.46	16.5
23	2.61	2.04	0.57	21.8

[1] Sex of birds not determined.

cent during a long span. Weight loss is most rapid during the first few days. In general, the heavier birds lose weight more rapidly than do the lighter ones, probably because initial weight loss results from food digestion, while subsequently it is due to the utilization of fat reserves.

Long incubation spans permit the birds to range widely between spans. Homing experiments (Kenyon and Rice, 1958) have revealed that albatrosses can cover more than 5,000 km in 10 days. Thus they could travel to any part of their North Pacific range and return during a normal 20- to 25-day period between incubation spans. One banded Laysan Albatross (U.S. 587–51729) incubating on 3 December 1956 was captured 22 days later 3,700 km away at 42°30′ N, 144°00′ E, off Hokkaido, Japan.

In length of incubation spans albatrosses exceed most other sea birds, and are equaled or exceeded only by certain species of penguins. The trend is carried to the extreme by the Emperor Penguin (*Aptenodytes forsteri*) of Antarctica, in which the male takes charge of the egg immediately after laying, and incubates continuously for the entire 62- to 64-day period (Stonehouse, 1960).

HATCHING

Hatching dates of 85 Black-footed Albatross eggs extended over a period of 24 days, from 15 January until 7 February (Figure 13). The mean time of hatching was 04:00 on 25 January (SE = 14 hr), with a standard deviation of 5.31 days. The modal dates were 25 and 26 January, the median 25 January.

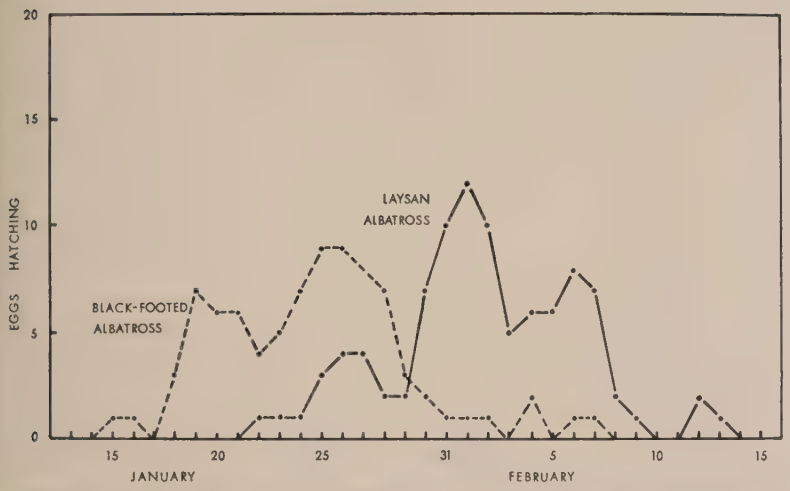

Figure 13. Hatching dates of 95 Laysan Albatross eggs and 85 Black-footed Albatross eggs at Midway Atoll in 1958.

The eggs of 95 Laysan Albatrosses hatched over a period of 23 days, extending from 22 January to 13 February (Figure 13). The mean time of hatching was 11:00 on 2 February (SE = 13 hr). The modal date was 1 February, the median 2 February.

The process of hatching is prolonged, as in other species among the lower orders, and requires from about 48 to 132 hours for completion. A typical example follows: The first tiny crack appeared on the surface near the large end of a Laysan Albatross egg on 27 January 1957 at 14:00; 19 hours later the bill protruded through a hole 10 × 3 mm; at 24 hours the hole measured 10 × 10 mm; at 51 hours, 20 × 50 mm; at 66 hours, 60 × 30 mm; and at 71 hours the shell had broken apart and the chick was working free of the membrane and shell fragments.

The eggs of 95 Laysan Albatrosses, examined twice daily, were pipped 59.0 to 65.0 days after laying (Table 12). The mean was 61.22 days (SD = 1.54; SE = 0.16). The mode and median was 61 days. Seventy-four Black-footed Albatross eggs, examined once daily, were pipped at 60 to 65 days after laying (Table 13). The mean was 62.57 (SD = 1.18; SE = 0.14). The mode and median was 62 days.

At 95 Laysan Albatross nests the chick was free of the shell 2.0 to 5.5 days after pipping (Table 14). The mean was 3.23 days (SD = 0.65; SE = 0.07). The mode and median was 3.0 days. At 82 Black-foot nests the eggs hatched one to five days after pipping (Table 15). The mean was 3.01 days (SD = 0.68; SE = 0.08). The mode and median was 3.0 days.

TABLE 12
INTERVAL BETWEEN LAYING AND PIPPING OF 95 LAYSAN ALBATROSS EGGS

Number of days	*Number of eggs*	*Per cent*
59.0	1	1.1
59.5	4	4.2
60.0	12	12.6
60.5	18	18.9
61.0	22	23.1
61.5	15	15.8
62.0	8	8.4
62.5	4	4.2
63.0	5	5.3
63.5	4	4.2
64.0		
64.5	1	1.1
65.0	1	1.1

PARENTAL CARE

Brooding and Attending

The nest life of an albatross chick is divided into two stages: the guard stage and the post-guard stage (Richdale, 1952). The guard stage is that period following hatching during which one parent remains at the nest with the chick.

For the first few days, while the chick is small and inactive, it is brooded by the parents. It grows rapidly, however, and soon becomes too large to be brooded comfortably. It also becomes more alert, and is not content to remain under the parent. Its head frequently protrudes from under the parent's breast, wing, or tail. When it gets too large to be brooded, one of the parents sits beside the nest and guards it. Or, if the parent is reluctant to leave the nest, the chick may build its own miniature nest beside the original nest.

The male and female share equally in guarding the chick. At 93 Laysan Albatross nests under regular observation for a total of 1,311.0 nest days from hatching until the chick was first left unattended, the male was guarding the chick 651.5 (49.69 per cent) days, the female 659.5 (50.31

TABLE 13
INTERVAL BETWEEN LAYING AND PIPPING OF 74 BLACK-FOOTED ALBATROSS EGGS

Number of days	*Number of eggs*	*Per cent*
60	1	1.4
61	12	16.2
62	27	36.5
63	17	23.0
64	12	16.2
65	5	6.8

TABLE 14
INTERVAL BETWEEN PIPPING AND HATCHING OF 95 LAYSAN ALBATROSS EGGS

Number of days	*Number of eggs*	*Per cent*
2.0	6	6.3
2.5	12	12.6
3.0	35	36.8
3.5	24	25.3
4.0	13	13.7
4.5	3	3.1
5.0	1	1.1
5.5	1	1.1

per cent) days. At 25 Black-foot nests under observation for 409.0 nest days, the male was on guard 211.0 (51.59 per cent) days, the female 198.0 (48.41 per cent) days. Therefore, we have not segregated by sex the data on length of guard spans (Tables 16 and 17).

Guard spans are much shorter than incubation spans. In both species, the first span following hatching averages less than three days. The longest recorded guard span was six days. There is a gradual but slight decrease in subsequent spans, to a mean of less than two days by the seventh span.

Laysan Albatross chicks were guarded continuously for three to 10 spans (M = 6.00; SD = 1.302; SE = 0.135) (Table 18); Black-foot chicks were guarded for five to 12 spans (M = 7.58; SD = 1.612; SE = 0.329) (Table 18).

Ninety-four Laysan chicks were first left unattended at 12.0 to 24.5 days of age (M = 17.18; SD = 2.47; SE = 0.26). Twenty-four Black-foot chicks were first left unattended at 12.5 to 24.5 days of age (M = 19.12; SD = 2.65; SE = 0.54).

Among 93 Laysan nests the male was the first to leave the chick unattended at 45 (48.4 per cent) nests, the female the first at 48 (51.6 per cent) nests. Among 24 Black-foot nests the male was first to leave at 14 (58.3 per cent) nests, the female at 10 (41.7 per cent) nests.

After the chicks are left unattended for the first time, they are guarded intermittently during another 10 days or so. Ninety-two Laysan chicks were guarded for the last time at 17.5 to 40.0 days of age (M = 27.29;

TABLE 15
INTERVAL BETWEEN PIPPING AND HATCHING OF 82 BLACK-FOOTED ALBATROSS EGGS

Number of days	*Number of eggs*	*Per cent*
1	1	1.2
2	13	15.9
3	53	64.6
4	14	17.1
5	1	1.2

TABLE 16
LENGTH OF GUARD SPANS OF LAYSAN ALBATROSSES[1]

Span number	*N*	*Number of days*			
		M	*SD*	*95% confidence interval*	*Range*
1	93	2.66	0.84	2.49–2.83	0.5–5.0
2	93	2.28	0.64	2.15–2.41	1.0–4.0
3	93	2.48	0.71	2.33–2.63	1.5–5.5
4	92	2.40	0.81	2.23–2.57	1.0–5.0
5	80	2.53	0.82	2.35–2.71	1.0–5.5
6	62	2.02	0.91	1.79–2.25	0.5–4.0
7	31	1.71	0.63	1.48–1.94	1.0–3.0
8	11	1.41	0.62	0.99–1.83	0.5–2.5
9	2	1.25			1.0–1.5
10	1	0.50			
Last[2]	93	1.94	1.16	1.70–2.18	0.5–5.5

[1] Does not include the intermittent spans subsequent to the time the chick is first left unattended.
[2] Span following which chick was first left unattended, regardless of number (includes, in part, spans 3 to 10).

SD = 4.67; SE = 0.49). The 24 Black-foot chicks were last guarded at an age of 21.5 to 42.5 days (M = 29.79; SD = 6.93; SE = 1.41).

During the post-guard period the parent birds visit the chick only briefly to feed it.

Feeding

The chick is fed by regurgitation, which is stimulated in the parent when the hungry chick pecks or "nibbles" at its bill. The chick inserts its bill

TABLE 17
LENGTH OF GUARD SPANS OF BLACK-FOOTED ALBATROSSES[1]

Span number	*N*	*Number of days*			
		M	*SD*	*95% confidence interval*	*Range*
1	24	2.83	1.29	2.29–3.37	0.5–5.5
2	24	2.50	0.72	2.20–2.80	1.0–4.5
3	24	2.15	0.71	1.85–2.45	0.5–3.5
4	24	1.98	0.77	1.65–2.31	0.5–3.0
5	24	2.00	0.98	1.59–2.41	0.5–4.5
6	23	2.54	1.23	2.01–3.07	0.5–6.0
7	19	1.84	0.96	1.38–2.30	0.5–4.0
8	8	2.31	0.92	1.56–3.06	1.5–4.0
9	7	1.93			0.5–4.0
10	3	1.83			0.5–4.0
11	1	2.50			
12	1	0.50			
Last[2]	24	1.98	1.54	1.33–2.63	0.5–6.0

[1] Does not include the intermittent spans subsequent to the time the chick is first left unattended.
[2] Span following which chick was first left unattended, regardless of number (includes, in part, spans 5 to 12).

TABLE 18

NUMBER OF GUARD SPANS FROM FIRST CHANGEOVER FOLLOWING HATCHING UNTIL CHICK WAS FIRST LEFT UNATTENDED

Number of spans	*Laysan Albatross*		*Black-footed Albatross*	
	No.	*Per cent*	*No.*	*Per cent*
3	1	1.1		
4	12	12.9		
5	18	19.4	1	4.2
6	31	33.3	4	16.7
7	20	21.5	11	45.8
8	9	9.7	1	4.2
9	1	1.1	4	16.7
10	1	1.1	2	8.3
11				
12			1	4.2

crosswise between the parent's mandibles, allowing the oil and partially digested stomach contents (which spurt as if from a hose nozzle) to pour into the distended throat (Figure 14). During a single feeding visit, which, after the guard stage, may last from 15 to 25 minutes, the parent may feed the chick three or four times.

While its parents are absent, a chick may wander over an area up to 30 meters in diameter and build a number of nests for itself, but it is always fed by returning parents at or near the original nest site.

Figure 14. The parent albatross is stimulated to regurgitate when the chick nibbles and pecks at its bill as illustrated here. KWK 995.

The following incident illustrates a typical feeding visit by a Laysan Albatross: On 18 June 1957 a marked chick rested in a nest it had constructed about 25 meters from its home nest. At 07:15 one of its parents returned from a feeding expedition at sea. At this stage in the breeding period, several days may elapse between feedings, and, in this case, the chick appeared quite hungry and anxious to be fed. It was directly in the path of the returning parent; as the parent approached, giving the Double-call, the chick answered and assumed begging posture. The parent, however, completely ignored the chick, hurried past it, and proceeded directly to the nest where it assumed the Yapping posture while uttering the Double-call. The chick, which had followed giving the begging '*peep-peep*' call, was recognized and subsequently fed by the parent only after it had taken position on the old nest. After feeding, the parent departed at 07:28.

After feeding their own chicks parents of both the Laysan and Black-footed albatrosses often rush to the nearest neighboring nest and attack the unattended young. While running to the attack a high-pitched shriek is uttered, the head is lowered and the neck extended. The chick being attacked exhibits Facing-away behavior, exposing the back of its neck to the attacking adult, which grasps the neck, shaking and pinching it vigorously for five to 10 seconds. Certain adults are more violent in their attacks than others. Young repeatedly attacked by such an adult may be bare of down and bloody on the back of the head and neck. Death sometimes occurs in such cases. In general, the attacks of Black-foots are more violent than those of Laysans. Submissive behavior is among the first behaviorisms expressed by the newly hatched chicks. Perhaps because the attack behavior is more violently expressed in the Black-foot than in the Laysan, submissive behavior is expressed earlier and with greater frequency in the newly hatched Black-foot than in the Laysan. Unfortunately, no quantitative behavior data were recorded.

The frequency of feeding was determined for 12 Laysan and five Black-foot chicks by weighing them twice daily during the first 30–40 days of life. If the chicks had been fed during the previous half day, an increase in weight was apparent. Weight records for two of these chicks have been graphed in Figures 15 and 16, which illustrate the relation between feeding frequency and the presence of the parents.

During the first two weeks or so following hatching, while the parents continually brood or guard the chick, they feed the chick frequently. During 186.0 nest days of observation of Laysan chicks, feeding was recorded 211 times, for an average interval of 0.88 days between feedings. During 71.0 nest days of observation of Black-foots, feeding was recorded 68 times, for an average interval of 1.04 days.

During the latter phase of the guard stage, when the parents guard the

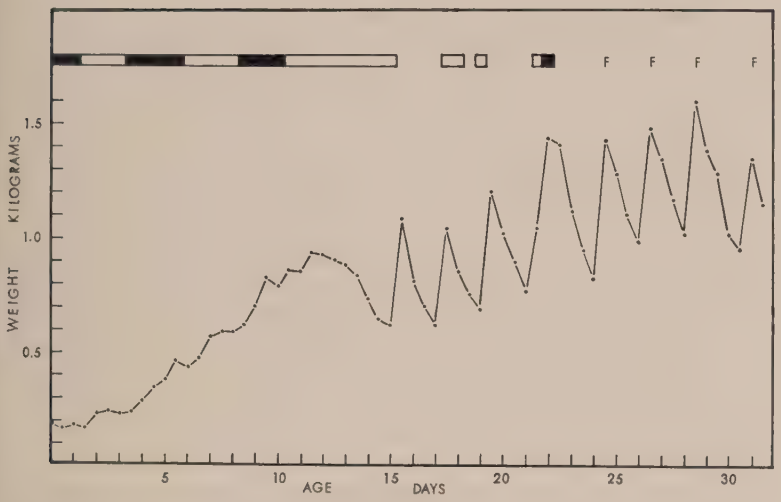

Figure 15. Parental care and weight of Laysan Albatross chick No. 99. Black bar=male guarding; white bar=female guarding; F=feeding visit.

chick only intermittently, feeding of Laysan chicks was recorded 56 times during 79.5 nest days of observation, for an average interval of 1.42 days. Feeding of Black-foot chicks was recorded 15 times during 29.5 nest days, an average interval of 1.97 days.

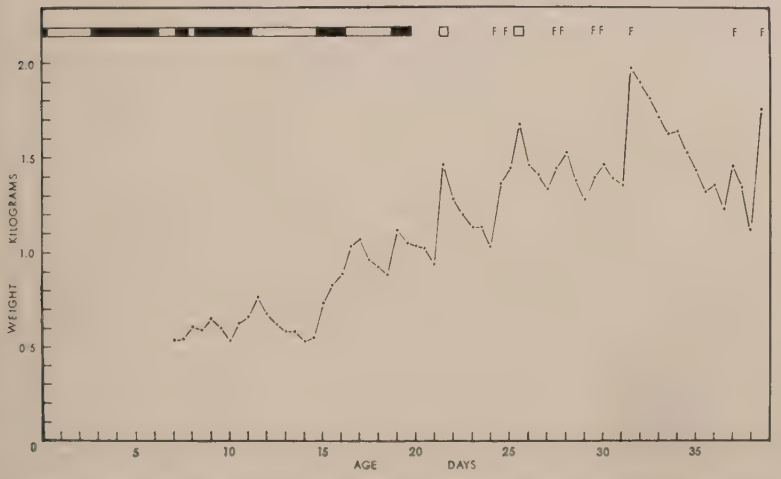

Figure 16. Parental care and weight of Black-footed Albatross chick No. 33. Black bar=male guarding; white bar=female guarding; F=feeding visit.

Following the end of the guard stage, the chicks are fed much less frequently. Observations of Laysan Albatross chicks totaling 66.5 nest days revealed only 27 feeding visits by the parents, or one every 2.46 days. Black-foot chicks, during 57.5 nest days, were fed 20 times, or once every 2.87 days.

General observations suggest that feeding visits become somewhat less frequent as the chick grows larger, but we have insufficient data to demonstrate this.

The chick is more often fed during daylight hours. Of 294 recorded feedings of Laysan chicks, 185 occurred during the 10 daylight hours, and 109 occurred during the 14 hours from dusk until dawn. Of 103 feedings of Black-foot chicks, 58 occurred during daylight, and 45 during darkness. Most of the "night" feedings probably occurred during the twilight or dawn hours.

Function of Stomach Oil

The origin and function of the stomach oil of procellariiform birds has been the subject of much controversy. Matthews (1949) has demonstrated that it is a secretion of the proventriculus, and he has reviewed all the hypotheses regarding its function, some of which appear quite imaginative. Our observations of albatrosses and several petrels and shearwaters demonstrate beyond question that the oil serves primarily as a food for the chick, and is thus analogous to pigeon milk; in some species (but not in albatrosses) it is secondarily utilized as a defense mechanism. In support of this theory we present the following facts:

1. Stomach oil is produced in quantity only by breeding albatrosses; it first appears near the end of the incubation period. Unemployed birds, and breeding birds during early stages of incubation, when roughly handled, may vomit mostly greenish bile or digestive fluids, or partially digested food, with no more than a trace of stomach oil.

2. Newly hatched chicks are fed exclusively with stomach oil for the first few days; the oil forms a large proportion of the diet of older chicks.

3. Albatrosses do not deliberately eject the oil for defensive purposes. When highly excited they may vomit up large quantities, but it is not directed at an intruder. (Some species of petrels apparently eject oil through the nostrils as a defensive action; albatrosses never eject the oil through their nostrils.)

4. The oil is definitely not used for preening. The plumage of albatrosses has a characteristic sweetish, rather pleasant, somewhat cowlike odor. Their stomach oil has a penetrating, nauseating, "fishy" odor, completely unlike that of the plumage, and it would be easily noticed if it were applied to the plumage.

Experiments should be conducted to determine the exact chemical composition of the oil, and its function in the nutrition of the chick.

Recognition between Parents and Young

Residents at Midway frequently move newly hatched, orphaned chicks to nests of pairs whose own egg or chick was destroyed; the foster chicks are readily accepted and cared for. Two quantitative studies were undertaken which indicated that up to about 10 days of age, at least, parents do not recognize their own chicks. By the time chicks have reached the age of six to seven weeks, most parents recognize their own young and will not feed a strange chick which has been exchanged for their own. (See Tinbergen, 1958: 145, regarding parental recognition among the Laridae.)

1. *Interspecific exchange of newly hatched chicks.* In an area where Black-footed and Laysan albatrosses nested in a mixed colony, young birds or eggs from five nests of each species were exchanged with eggs or chicks of comparable age of the other species. The exchanges were made on 5 February 1957 as follows: (1) Two pairs of nests—eggs exchanged; (2) two pairs of nests—newly hatched young exchanged; (3) one pair of nests—young about 10 days old exchanged. Sixteen observations were made at intervals of two to four days, the last on 8 April, 63 days after the exchange.

All eggs and young were apparently accepted by their foster parents. However, two Black-foot chicks, newly hatched when exchanged, died, apparently of starvation, one on the 6th day after the exchange and the other on the 49th day. When observations were terminated, all remaining young appeared to be in excellent condition.

It was observed in several instances that when a Laysan parent was feeding a Black-foot chick, the feeding foster parent appeared disturbed by the chick's behavior, which is more aggressive and "rough" than in the Laysan chick. The fact that no Laysan chicks given to Black-foot foster parents died, while two Black-foot chicks given to Laysan foster parents did die, may indicate that, in individual cases, the difference in behavior of the Black-foot chicks disturbed the foster parent Laysan Albatrosses to the extent that feeding was inhibited. Other Laysan foster parents, however, appeared to become well adapted to the behavior of their foster young, which they reared in excellent health. The experiment, however, was conducted on such a small scale that a positive conclusion could not be drawn.

The observations were discontinued primarily because time was needed for other studies. The chicks, at about the age of two months, often wandered 10 to 20 meters from their nests and sought shelter under

Scaevola bushes, so that much time was required to find them and read their leg bands.

One Black-foot chick that was raised by Laysan foster parents on the Post Office lawn during the 1958 season was an exceptionally healthy individual, and was successfully fledged.

2. *Intraspecific exchange of older chicks.* On 20 March two plots about 25 meters apart were selected on Eastern Island. Ten young Laysan Albatrosses, about six to seven weeks old, from one plot were exchanged for 10 young of comparable size and age from the other. The birds were each marked with regulation leg bands and red dye. Each of the 20 nests was marked with a numbered stake. An hour after being placed in the strange nests, 10 of the young had moved out of them, several as far as two meters. All were replaced in their foster nests, and most remained in or near them until the study was discontinued on 23 May. After the nest exchange on 20 March, only one chick returned to its original nest, and it was returned to its foster nest on 23 March. The young were first weighed on 23 March and were subsequently weighed on 14 occasions.

Among the 20 chicks given to foster parents, 12 were never fed, and starved to death. The mean survival time was about 22 days, with extremes of eight and 36 days. The other eight chicks were fed regularly, presumably by the adults in whose nests they were placed. The mean gain in weight in 68 days was 0.72 kg; the minimum gain was 0.36 kg, and the maximum gain was 1.42 kg. One individual, although fed on several occasions, showed a net loss of 0.25 kg at the end of the study period. Although still in apparently good health when the study terminated, there appeared little chance that it, and even others showing some weight gain, would ultimately survive. To be conclusive this experiment should have been carried on until all young had left or died. It is probable that some young, being fed by only one foster parent, would have survived until the feeding cycle of the attending adult terminated, and then would have died because of retarded development.

It is concluded that at this age, recognition of chicks by their parents has become established to the extent that over half of the parents failed to feed a strange chick substituted for their own.

The parents definitely recognize their chick when it is older, and strange chicks are attacked (see Feeding).

Older chicks also recognize their parents. When a parent bird returns from the sea and alights near the nest, the chick, which may be 30 meters away, immediately rushes up to the parent and begins begging. Other adults it ignores. Starving chicks, however, will beg from any adult passing nearby.

Nest Sanitation

When defecating, nestling albatrosses raise the posterior part of the body and eject the feces in a forceful stream a meter or more beyond the nest. Thus the nest is kept clean. This behaviorism is present in the chick at hatching. The small quantity of feces emitted by both incubating and young albatrosses is surprising when compared in general with that of other marine birds.

Nest Defense

During the guard stage, as during incubation, adult albatrosses will snap at and attempt to bite intruders—whether they be men, dogs, or other albatrosses. (All dogs on Midway soon learn to ignore albatrosses, both adults and chicks.) Albatross chicks are much more aggressive than are their parents. They keep up a rapid, continuous snapping of the beak when approached closely. While Snapping, Black-foot chicks usually utter a snorting nasal grunt, which corresponds to the Yammer of the adult, but Laysan chicks are usually silent.

DEVELOPMENT OF YOUNG

Newly hatched albatrosses are altricial, nidicolous, and ptilopaedic.

Growth

The bill, wing, tarsus, and middle toe of 10 Laysan and five Black-footed albatross chicks were measured at five-day intervals from hatching until age 75 days, by which time they had nearly attained adult weight (Figure 17). The rate of weight increase of these chicks is illustrated in Figure 18. Other duties prevented the continuation of these observations until the chicks were fledged.

Plumages

The plumages and plumage sequence of Laysan and Black-footed albatross chicks appear almost identical. The only obvious difference is the lighter coloration of the Black-foot chicks, due to more extensive white tips on the down. The bill of the newly hatched Laysan chick is blue-gray, that of the Black-foot is black.

The gray, white-tipped natal down is moderately long, loose, and ragged, with a distinct peppercorn appearance (Figure 19). Almost immediately after hatching, the mesoptiles begin to grow, the protoptiles remaining attached to their tips. By the end of the guard stage, the chick is covered with the long and very dense coat of secondary down, still retaining the peppercorn appearance.

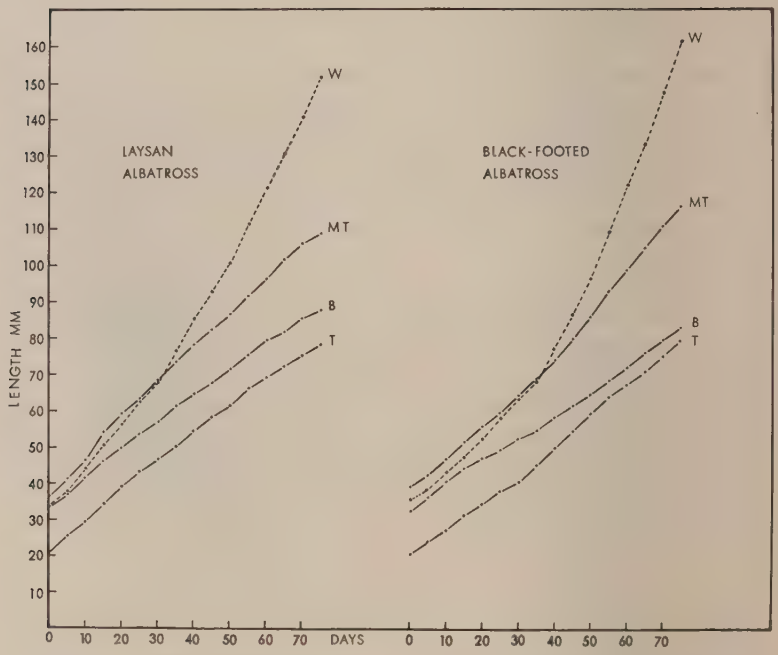

Figure 17. Mean growth curves of 10 Laysan and five Black-footed albatross chicks from hatching to age 75 days. W=wing, MT=middle toe, B=bill (culmen), T=tarsus.

The primaries begin to sprout at about 35 days of age. By March the growing teleoptiles are well developed on the breast, but are evident only when the down is parted. The mesoptiles remain firmly attached until late April or early May. The down is first lost from the back and the sides, then from the belly. The upper breast, neck, and head are the last areas to lose the down (Figure 20). In general, the molt works upward in this area, and the head may retain some down at fledging.

The plumages of the fledglings are almost identical to those of the adults. Fledgling Laysans may have a few grayish feathers on the upper thighs, and gray flecks on the crown; their bills are gray, rather than orange as in the adults. Fledgling Black-foots never show the white rump markings, which are characteristic of most adults.

Temperature Regulation

An experiment was conducted to determine the age at which albatross chicks attain the ability to maintain a relatively constant body temperature. A series of 19 young Black-footed Albatrosses of known age,

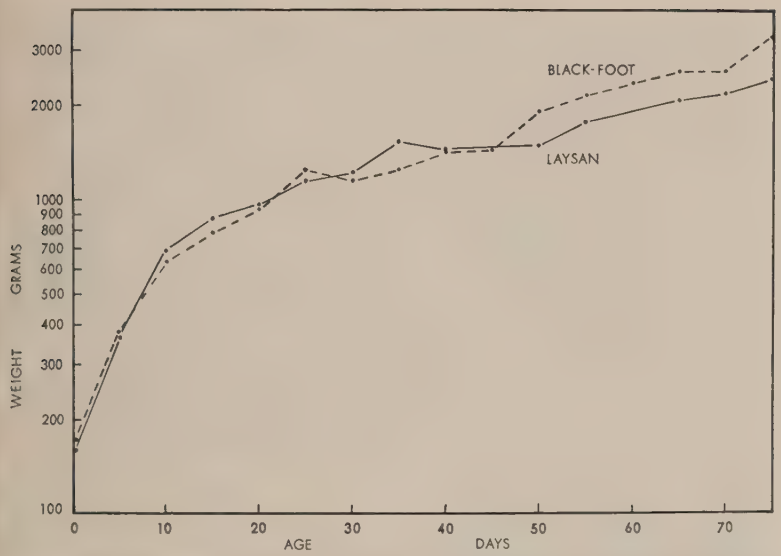

Figure 18. Mean weights at five-day intervals of 10 Laysan and five Black-footed albatross chicks from hatching to age 75 days.

Figure 19. The natal down is white tipped, and has a peppercorn appearance. These Black-footed Albatross chicks rest in excavations which they form by frequently kicking sand backwards. Streaks of excrement may be seen on the sand near the nests. KWK 991.

Figure 20. A fledgling Laysan Albatross illustrates the last stages of molt shortly before departure from the nesting ground. DWR 1001.

varying from 0 to 22 days, was selected. The rectal temperature of each was recorded, and they were then removed from their nests and placed in the shade of nearby *Scaevola* bushes. At the time the air temperature in the shade was 20.6° C, and the ground temperature was 17.8° C. After 30 minutes, the rectal temperature of each bird was again recorded, and a notation made as to whether or not it was shivering. Each bird was then returned to its nest.

The body temperature of the younger birds dropped slightly more than that of the older birds (Table 19). Chicks 0 to 11 days old dropped a mean of 2.0° C, while chicks 12 to 22 days old dropped a mean of 1.3° C. The chicks up to about 18 days old, which were still being brooded by one of their parents, shivered when placed in the shade. The older chicks, which were no longer being brooded, did not shiver. The drop in the body

TABLE 19
RECTAL TEMPERATURES OF BLACK-FOOTED ALBATROSS CHICKS DURING EXPERIMENT IN THERMOREGULATION

Age (days)	*Brooded*	*Rectal temperature (°C)*			
		At start	*After 30 min in shade*	*Change*	*Shivering*
0	yes	37.4	34.5	−2.9	yes
2	yes	38.2	35.6	−2.6	yes
4	yes	38.2	36.5	−1.7	yes
6	yes	37.7	35.8	−1.9	yes
7	yes	37.8	36.5	−1.3	yes
8	yes	37.7	37.0	−0.7	yes
9	yes	38.8	36.0	−2.8	yes
10	yes	39.3	37.3	−2.0	yes
11	yes	38.0	35.7	−2.3	yes
12	yes	37.7	36.5	−1.2	yes
13	yes	38.2	37.7	−0.5	no
14	yes	37.8	37.7	−0.1	yes
15	yes	39.0	36.5	−2.5	yes
16	yes	38.4	36.5	−1.9	yes
17	yes	38.2	36.5	−1.7	yes
18	no	38.7[1]	36.7	−2.0	yes
19	no	39.1[1]	37.4	−1.7	no
21	yes	38.1	37.7	−0.4	no
22	no	38.8[1]	38.4	−0.4	no

[1] Nest site in direct sunlight.

temperature of the older unbrooded chicks may be explained by the fact that the nest sites from which they were removed were in direct sunlight.

It thus appears that Black-footed Albatross chicks attain the ability to maintain a normal body temperature without shivering at an age of about 18 to 20 days, at the time the parents cease to brood them.

As the chicks grow older and the weather grows hotter, they are faced with the problem of keeping cool. This is facilitated by three behavioral adaptations:

1. *Seeking shade.* During hot afternoons albatross chicks often seek the shade of bushes, if any are nearby. They will go as far as 25 meters from the nest site. They always return to the nest site toward sundown.

2. *Panting.* Albatross chicks pant vigorously in hot weather. The beak is held open, and the gular region is distended and pulsates, resulting in evaporative cooling in the throat.

3. *Raising the feet.* During clear weather the sand or coral rock and rubble becomes very hot due to the absorption of radiant heat from the sun. To avoid conduction of this heat through the large area of webbing on ther feet, young albatrosses assume a characteristic posture. They rest on their heels (tibio-tarsal joints) and raise their feet about 3 to 10 cm above the surface of the ground. If there is a breeze blowing, this may also permit evaporative cooling on the surfaces of the web.

The body (rectal) temperatures of 20 adult albatrosses of each species

TABLE 20
RECTAL TEMPERATURES (°C) OF ADULT ALBATROSSES

Species and status	*Mean*	*Range*
Laysan Albatross (10 incubating)	37.6	36.9–38.6
" " (10 unemployed)	39.4	37.7–40.2
Black-footed Albatross (10 incubating)	39.0	38.6–39.7
" " " (10 unemployed)	39.0	37.7–40.2

were taken. Ten individuals of each species were incubating or brooding; the other 10 were unemployed. The results are presented in Table 20.

The markedly lower temperature of the incubating Laysan Albatrosses is perhaps due to the fact that their nests were built in the shade on moist organic soils, whereas the incubating Black-foots were in direct sunlight on dry coral sand.

Since the above was written, Howell and Bartholomew (1961) have published the results of a more detailed study of thermoregulation in Midway Island albatrosses.

FLEDGING

Length of Nestling Stage

The mean length of the nestling stage, calculated from hatching dates and departure dates (see below), is 165 days in the Laysan Albatross, and about 140 days in the Black-footed Albatross. Unfortunately, we have no data on the exact age of individual birds at fledging.

The "Starvation Period"

Richdale (1954) has marshaled convincing evidence that refutes the theory of the "starvation period," insofar as it applies to the Royal Albatross and the Wandering Albatross (*D. exulans*). (There is apparently a true starvation period prior to fledging in several species of the family Procellariidae.) We found that there is normally no starvation period in Laysan and Black-footed albatrosses. Most of the chicks were fed until they were able to fly and to leave the island.

During June and July, however, many emaciated chicks were found along the beaches. These were chicks that had left their nest sites before they were able to fly efficiently, and were no longer fed by their parents. The majority of these chicks died. Some of them had considerable amounts of down attached to their feathers; when they made feeble efforts to fly away, they floundered in the lagoon, became waterlogged, and drowned; many were washed ashore. Others simply remained on the beaches and starved to death.

Figure 21. Departure of young Laysan Albatrosses from study plot at Midway Atoll, 1957.

Departure from the Island

Prior to departure, the young birds strengthen their wings for several weeks by spreading them in the breeze, flapping them, and making short, exploratory flights of a few meters. Before final departure the young birds may make several brief flights during which they may alight on the lagoon before returning again to the beach.

The dates of departure of 54 young Laysan Albatrosses from a sample plot are shown in Figure 21. Young Black-foots depart on the average about 30 days ahead of the Laysans. The adults cease to visit the breeding grounds at the time the chicks are fledged.

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The U.S. Navy financed these studies. Captains J. A. Gammon, Jr., and E. T. Hughes, Commanding Officers of the U.S. Naval Station, Midway Islands, authorized field assistance and transportation. J. W. Aldrich, J. A. Neff, C. S. Robbins, W. C. Royall, Jr., R. Stockstad, R. T. Takahashi, and R. E. Warner assisted in the field work. T. Thorslund made the statistical computations.

SUMMARY

Laysan Albatrosses (*Diomedea immutabilis*) and Black-footed Albatrosses (*D. nigripes*) were studied throughout two successive nesting

seasons at Midway Atoll in the Leeward Chain of the Hawaiian Islands.

Both species may first return to the breeding grounds at an age of three (rarely two) years. They may breed when they are seven years old but most apparently do not nest until they are older. Adults normally breed annually.

Black-footed Albatrosses begin to arrive on the breeding grounds about 18 October, Laysan Albatrosses about 1 November. Females arrive, on the average, about five days later than males.

Unmated pairs "keep company" for a year or more before the pair bond is consummated. The pair bond normally remains intact year after year unless broken by the death or disappearance of one of the partners.

Laysans and Black-foots use homologous vocalizations, but the calls of the latter species are lower pitched, louder, and have a nasal quality. Vocalizations of the adult include the Whinny, Whine, Moo, Double-call, and Yammer. Likewise, the ritualized display postures of the two species are homologous, with minor differences. These include (using Richdale's terminology where applicable) Bowing, Gawky-look, Billing, Mouthing, Yapping, Snapping, Clappering, Whinnying, Head-shake-and-whine, Sky-call, Head-up-and-whine, Scapular-action, and Head-up-and-clap.

The Dance is a mutual gamosematic and epigamic display indulged in by breeding pairs prior to nest building, and by unemployed birds throughout the breeding season. The Dance consists, in varying sequence, of Clappering, Whinnying, the Scapular-action, the Head-up-and-clap, and, less frequently, the Head-shake-and-whine, the Sky-call, and the Head-up-and-whine.

Territory is confined to the immediate vicinity of the nest and is used only for mating and nesting. Birds normally return to the atoll on which they were reared, but not to their exact hatching site, to establish nesting territory. Once established, a territory is held for life. Attachment to a site is so strong that birds deserted their nests and eggs or chicks when these were experimentally displaced more than two meters.

Both sexes build the nest, beginning one to three days before the egg is laid. The nest is of the directly adaptive type, consisting of a depression in the substratum surrounded by a raised rim.

Only one egg is laid each year; if destroyed, it is not replaced. Experiments showed that birds cannot successfully incubate two eggs; pairs are unable to raise two chicks; neither can a single adult successfully rear a chick. The mean date for egg laying by Black-foots was 21 November (range: 8 to 30 November); the mean date for Laysans was 30 November (range: 15 November to 16 December).

The incubation period is 64.4 days in the Laysan, 65.6 days in the Black-foot; the difference is statistically significant ($P < 0.001$). Both

sexes incubate. Incubation is continual. The female is usually relieved within three or four days after egg laying. The first span by the male averages 22.6 days in the Laysan, 18.2 days in the Black-foot. Subsequent spans are successively shorter; the last span averages 8.3 days in the Laysan, 7.2 days in the Black-foot. The mean number of spans required to complete incubation is 5.0 in the Laysan, 6.2 in the Black-foot.

The mean hatching date for Black-foots was 25 January (range: 15 January to 7 February); for Laysans, 2 February (range: 22 January to 13 February). The interval between pipping and hatching is 48 to 132 hours.

Laysan chicks are guarded continually by one parent until they reach a mean age of 17.2 days (range: 12.0 to 24.5 days), and then intermittently until the age of 27.3 days (range 17.5 to 40.0 days). Black-foot chicks are guarded continually until the age of 19.1 days (range: 12.5 to 24.5 days), intermittently until the age of 29.8 days (range: 21.5 to 42.5 days). The parents alternate in guarding the chick; the first and last guard spans, respectively, average 2.7 and 1.9 days in the Laysan, 2.8 and 2.0 in the Black-foot.

Chicks are fed by regurgitation. Stomach oil is their sole food for the first few days. During the early part of the guard stage, they are fed at least once every day; during the early post-guard stage, they are fed on the average of once every 2.5 days (Laysans) or 2.9 days (Black-foots). Experiments revealed that until the chicks are about 10 days old they are not recognized by their parents, who up to then readily accept foster chicks. As the chicks grow older, there is mutual recognition between parents and young; parents will feed only their own chick, and chicks normally beg only from their parents.

At hatching chicks are altricial, nidicolous, and ptilopaedic. They weigh an average of 0.16 kg; they grow rapidly, and by 75 days of age, Laysans average 2.23 kg, Black-foots 3.33 kg. The protoptiles are replaced by the mesoptiles soon after hatching. The primaries sprout at about 35 days. By 75 days the growing teleoptiles are evident under the down, which begins to be shed at about 120 days, starting on the breast. At fledging (140 to 165 days) some down may still cling to the head and upper neck.

At about 18 days of age unbrooded chicks can maintain a normal body temperature without shivering. Older chicks keep cool during hot weather by seeking shade, panting, and raising their feet off the ground.

The mean length of the nestling stage is about 165 days in the Laysan, about 140 days in the Black-foot. There is no "starvation period"; chicks are normally fed until they are fledged; those that are not almost always starve to death. Chicks make short practice flights before final departure,

which averages about the middle of June for Black-foots, a month later for Laysans.

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SUPPLEMENTARY NOTE

Chandler S. Robbins has informed us (*in litt.*, 9 August 1962) that during the 1961–1962 season he found four five-year-old Black-footed Albatrosses nesting. These were birds that we had color banded as nestlings on Eastern Island, Midway Atoll, in the 1956–1957 season; he found two nesting at Midway Atoll (one on Eastern Island, one on Sand Island) and two at Kure Atoll, about 100 km northwest of Midway. Many other members of this year class also returned to Midway during the 1961–1962 season, but did not nest.

U.S. Fish and Wildlife Service, Sand Point Naval Air Station, Bldg. 192, Seattle 15, Washington.

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BREEDING DISTRIBUTION, HISTORY, AND POPULATIONS OF NORTH PACIFIC ALBATROSSES

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Sir:

Following the publication of our paper on "Breeding distribution, history, and populations of North Pacific albatrosses" (*Auk*, 79: 365–386, 1962), Dr. Christian Jouanin of the Museum National d'Histoire Naturelle, Paris, has written us as follows: "May I draw your attention [to] a point which has been overlooked by every reviewer in spite of a publication by Oustalet in 1895 [Les Mammifères et les Oiseaux des Îles Mariannes. Nouv. Arch. Mus. Hist. nat. (3)7: 141–228 and 8: 25–74]? The bird collections of the Paris Museum include several skins and eggs of *Diomedea nigripes* collected by Alfred March in the Mariannas, which attest without doubt that a colony of Black-footed Albatrosses bred at Agrigan during the last century. . . . I published on this subject in 1959 [Une colonie méconnue d'Albatros a pieds noirs, *Diomedea nigripes*, dans les iles Mariannes. Bull. Mus. nat. Hist. nat. Paris (2)31: 477–480]."

Agrihan (as it is spelled on National Geographic Society maps) is located in the northern Mariana Islands at 18° 45′ N lat., 145° 45′ E long.

We are grateful to Dr. Jouanin for bringing this to our attention.—Dale W. Rice and Karl W. Kenyon.

BREEDING DISTRIBUTION, HISTORY, AND POPULATIONS OF NORTH PACIFIC ALBATROSSES

Dale W. Rice and Karl W. Kenyon

Albatrosses, the largest and most spectacular sea birds, have received little intensive long-range study, chiefly because they nest on remote, uninhabited oceanic islands. Much of our knowledge of the life history of these birds comes from the classic studies of L. E. Richdale (1950, 1952) on the Royal Albatross (*Diomedea epomophora*) in New Zealand. In order to gain knowledge of the habits of albatrosses that interfered with aircraft operations at Midway Atoll, the U.S. Navy financed a study of these birds. Rice spent from 17 November 1956 to 21 July 1958, and Kenyon from 29 December 1956 to 26 June 1957, in the Leeward Hawaiian Islands. In this period we made an intensive study of the Laysan Albatross (*D. immutabilis*) and a less intensive study of the Black-footed Albatross (*D. nigripes*) on Midway Atoll, and surveyed all known breeding colonies throughout the Leeward Chain. This report traces the historical records of population fluctuations and summarizes our data on the present populations of these two species. The breeding cycle and distribution at sea will be treated in later publications. The history of the third species of North Pacific albatross, the Short-tailed Albatross (*D. albatrus*), was reviewed by Austin (1949); during the 1958–1959 season the entire world population included 18 nesting pairs, all on Tori Shima (Fauna Preservation Society, 1960).

Methods

We determined the size of nesting albatross populations by (1) aerial surveys, and (2) ground counts.

1. Aerial surveys were conducted at all the Leeward Hawaiian Islands during the incubation period (late November and December). The aircraft were Navy UF-1 Grumman Albatross amphibians. A series of passes was made over each island at an altitude of 60 to 150 meters, at a speed of 220 km per hour. During each run, an overlapping series of oblique photographs was taken from the side hatch with an F-56 Fairchild camera, which exposed 17.5 × 17.5 cm negatives.

A contact print was made from each negative. Each series of photographs was oriented by means of landmarks, and areas of overlapping coverage were blocked out. Each photograph was examined under a magnifying lens, or a 10× binocular microscope. As each albatross was counted it was pricked with a pin, to avoid duplication or omission.

In most cases it was impossible to distinguish between incubating and unemployed birds. Ground counts made at Midway, a few days prior to

the aerial surveys, indicated that 25 per cent of the albatrosses visible on the photographs were unemployed. Therefore, we reduced our counts by 25 per cent to estimate the number of nests.

On certain areas complete counts were impossible because many birds were hidden by vegetation. Here we estimated numbers by comparing the photographs with photographs of comparable terrain on Eastern Island where the number of nests per unit of area had been determined by ground counts.

On all islands nearly complete counts of Black-footed Albatrosses were possible because they inhabit open terrain.

2. Ground counts were conducted in two ways. Where practicable, all nests were counted. Where Laysan Albatross nests were highly concentrated, duplication and omission were avoided by marking each incubating bird on the breast with a spot of red dye. The dye was applied from a bottle having a cotton wick inserted through a small hole in the cap; the bottle was attached to the end of a meter-long stick. Deserted nests containing eggs were also counted. A Veeder-Root hand tally was used to prevent errors in counting.

Where complete counts were impractical, sample plots were counted, and an estimate for the total area was extrapolated. Details are given below under the accounts for each island.

RESULTS

The known and probable breeding distribution, within historical times, of the three species of *Diomedea* occurring in (and endemic to) the North Pacific is summarized in Table 1. The authorities for the inclusion of each island or atoll within the range of *D. immutabilis* and *D. nigripes* are cited below. The range of *D. albatrus,* presented for comparison, is summarized from Austin's (1949) account. The breeding distribution of each species is plotted on the accompanying map (Figure 1).

Our estimates of present breeding populations, expressed as number of occupied nests at the beginning of the nesting season, are summarized in Table 2. Estimates have been rounded to the nearest two significant digits, as the accuracy of the census methods does not justify more precise figures.

The five outer atolls (Kure, Midway, Pearl and Hermes, Lisianski, and Laysan) of the Leeward Chain were surveyed both years; the inner four islands of the Leeward Chain, and Kaula of the main group, were surveyed only in the 1957–1958 season.

The number following the name of each island refers to the map (Figure 1).

Hawaiian Islands

Kure Atoll (1). Green Island is the only albatross breeding ground on this

westernmost atoll of the Hawaiian Island chain. Wetmore obtained observations on Kure from 17 to 22 April 1923. Of the Black-footed Albatross he says (*in litt.*): "300 pairs, in small colonies on sandspits and small areas of beach. Many dead adult birds seen, cause of mortality unknown."

TABLE 1

SUMMARY OF DISTRIBUTION OF NORTH PACIFIC ALBATROSSES[1]

Island or atoll	*Diomedea albatrus*	*Diomedea nigripes*	*Diomedea immutabilis*
1. Hawaiian Islands: Kure Atoll		X	X
2. " " Midway Atoll		X	X
3. " " Pearl and Hermes Reef		X	X
4. " " Lisianski Is.		X	X
5. " " Laysan Is.		X	X
6. " " Gardner Pinnacles			X
7. " " French Frigate Shoals		X	X
8. " " Necker Is.		X	X
9. " " Nihoa Is.		X	X
10. " " Kaula Is.		X	
11. " " Niihau Is.			X
12. " " Moku Manu			(X)
13. Johnston Island		(X)	(X)
14. Marshall Islands: Taongi Atoll		(X)	
15. Wake Island		(X)	(X)
16. Marcus Island		(X)	(X)
17. Izu Islands: Torishima	X	X	(X)
18. Bonin Islands: Kita-no-shima	(X)		
19. " " Muko-shima	(X)	(X)	
20. " " Yome-shima	(X)		
21. " " Nishi-no-shima	(X)		
22. Volcano Islands: Iwo Jima		(X)	
23. Daito Islands: Rasa Is.	(X)		
24. Ryu-kyu Islands: Kobisho	(X)		
25. " " Agincourt Is.	(X)		
26. Pescadores Islands: Byo-sho	(X)		

[1] X = occurs; (X) = extirpated.

And, of the Laysan Albatross: "50 pairs, nesting on the beach around Green Island, alone, or in company with groups of *D. nigripes*. The small open area in the center of the island was a trap in which I found bodies of a dozen that had alighted there and then had not been able to take flight again." In 1957 we found several skeletons of albatrosses that had become entangled in the *Scaevola* thickets that surround the central open area, and had died of starvation. An effort was made by the Navy in 1959 to improve albatross nesting habitat on the island. With bulldozers, passages were cleared through the heavy growth of *Scaevola* to give albatrosses improved access to and from the ideal nesting sites in the island's interior.

During ground surveys, we counted 270 Laysan and 42 Black-foot chicks on 5 June 1957, and about 300 and 50, respectively, on 9 May 1958. Allowing for nest mortality, we estimate about 350 Laysan and 70 Black-foot nests at the beginning of each season (Kenyon and Rice, 1958).

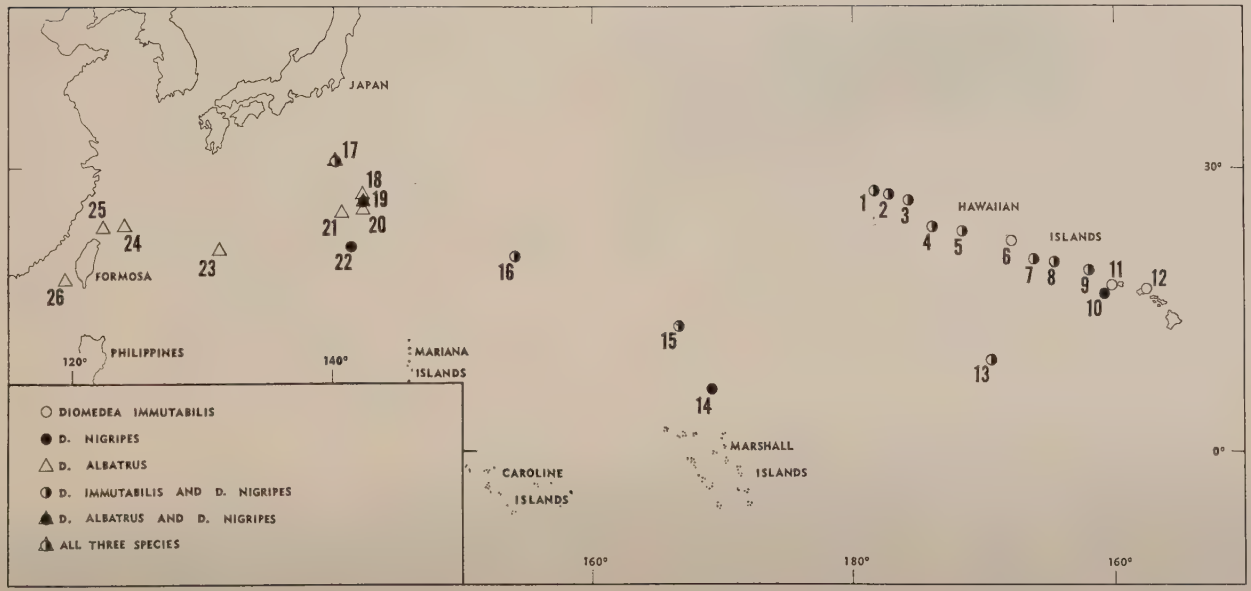

Figure 1. Map of the past and present breeding distribution of the three North Pacific species of *Diomedea*. See Table 1 for key to geographical locations.

TABLE 2

ESTIMATED NUMBER OF NESTING PAIRS OF ALBATROSSES IN THE HAWAIIAN ARCHIPELAGO DURING THE 1956–1957 AND 1957–1958 SEASONS

Island	*D. immutabilis*	*D. nigripes*
Kure Atoll		
Green Island	350	70
Midway Atoll		
Sand Island	60,000	6,300
Seal Islet	30	–
Rocky Islet	25	–
Eastern Island	40,000	2,400
Pearl and Hermes Reef		
Kittery Island	–	450
Seal Island	450	370
Grass Island	1,200	1,900
south sandspits	–	63
Southeast Island	14,000	2,300
north sandspits	–	120
North Island	2,100	1,900
Lisianski Island	30,000	2,700
Laysan Island	130,000	34,000
Gardner Pinnacles	2	–
French Frigate Shoals		
Tern Island	24	2
Trig Island	100	130
Whale Island	260	840
Round Island	–	12
East Island	200	170
Gin Island	–	3
Little Gin Island	–	340
Disappearing Island	–	2
Necker Island	2,500	370
Nihoa	500	50
Kaula	–	100
Niihau	500	–
Moku Manu	0	–
Total pairs	282,241	54,592
Rounded	280,000	55,000
Total nesting birds	560,000	110,000

In 1960 construction of a Coast Guard radio station on Kure was begun.

Midway Atoll (2). Two large islands (Sand and Eastern), three small islets, several shifting sandspits, and a surrounding reef constitute the dry-land area of this atoll. Sand and Eastern islands are the only important bird-nesting islands. Up to the time of this study Midway was the only one of the Leeward Hawaiian group having a permanent human population. A cable station was established there in 1903, and Pan American Airways established a base there in 1935. The atoll has been under the jurisdiction of the Navy Department since 20 January 1903, and was made a national defense area on 14 February 1941. Much of the five square km of Sand and Eastern islands are now occupied by the U.S. Naval Station.

When Munro (1942) visited Sand Island in 1891, he wrote that it was

an "indescribably desolate, lonely isle. I . . . looked over the large expanse of white sand . . . broken only by a few green mounds of *Scaevola* bushes . . . the moans of the solitary petrel and the occasional harsh squawk of the tropic bird under the house, the total absence of other birds . . . was depressing."

Cable Company employees introduced earth, garden plants, shrubs, and trees. Mr. George Willett visited Sand Island on 14 March 1913, and recorded in his notes (Bailey, 1956) that "A few Laysan Albatrosses were nesting near the houses and on the beach at the opposite end of the island were small colonies of Black-footed Albatrosses." In the late 1930's Hadden (1941) stated: "There are over 2,000 [Laysan Albatrosses] in the P.A.A. compound by actual count." Munro (1943) observed: "The transformation of Sand Island of Midway from a desolate desert isle to a pleasant little countryside, and from a birdless island to one carrying an extraordinarily large bird population is largely due to the Commercial Pacific Cable Company and Mr. and Mrs. Daniel Morrison." More detailed historical information is given by Hadden (1941), Bryan (1942), Fisher and Baldwin (1946), Fisher (1949), and Bailey (1952). Wetmore was at Midway 23–24 April 1923. He estimated (*in litt.*) that on Eastern Island there were 1,000 pairs of Black-foots and "1,500+ pairs [of Laysans] that nested mainly in long openings in the brush cover. My notes state it was difficult to judge their numbers but there were certainly more than 1,500 pairs, all with well-grown young. (The total however could not have been more than 1,800 pairs, if that many.)" On Sand Island he estimated 1,000 pairs of Black-foots and 1,000+ pairs of Laysans.

In the late 1930's Hadden estimated the albatross population on Midway (presumably Sand Island only) at 20,000 Laysan and 30,000 Black-footed albatrosses. As vegetation spread, the more adaptable Laysan continued to increase. The Black-foot population apparently reached a maximum of nearly 20,000 pairs in the early 1940's, after which it declined. Whether the decline was the result of wartime activity or a result of ecological conditions is a moot question. We suspect that the early stages of vegetation growth, between 1903 and the late 1930's, gave needed protection from blowing sand, causing a population increase. Maximum vegetation development during the 1940's and 1950's, however, destroyed the open areas preferred by the Black-foot. Wartime destruction of birds and decreased nesting habitat apparently combined to stabilize the population at about 5,000 to 6,000 nesting pairs in the late 1950's. It is beyond question that planting on Sand Island, which furnished shelter to nesting albatrosses, was directly responsible for the growth of the population, particularly of the Laysan Albatross, from a

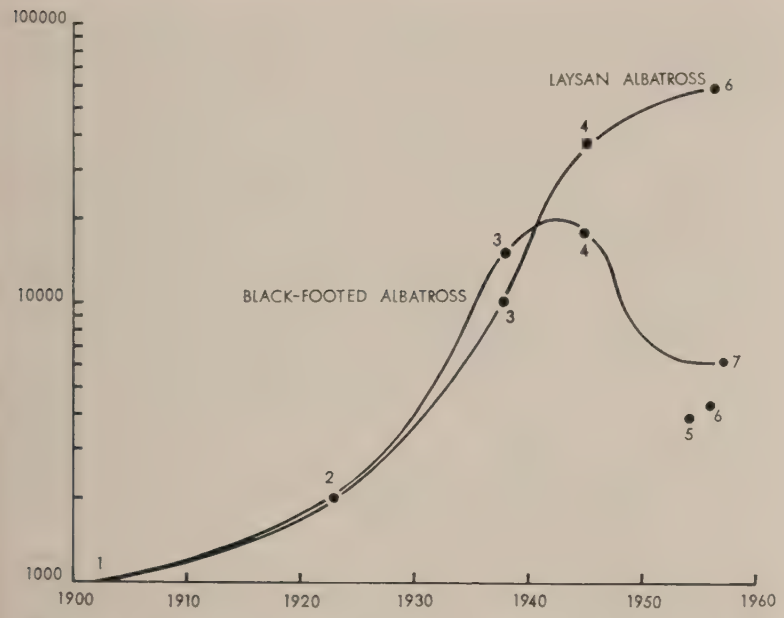

Figure 2. Dots represent estimates of nesting pairs of Laysan and Black-footed albatrosses on Sand Island, Midway Atoll. Estimates are few and were obtained by different means, but indicate a general order of magnitude of the two populations. The hypothetical population curves are drawn by eye. References are: (1) prior to 1903 (Munro, 1942); (2) 1923 (Wetmore, *in litt.*); (3) late 1930's (Hadden, 1941); (4) May, 1945 (Fisher and Baldwin, 1946); (5) Dumont and Neff (MS., 1955) estimate of December 1954; (6) our 1956–1957 estimates; the Black-footed Albatross nest estimate based on a late season count may have been inadequately corrected for early season nest mortality; (7) December 1957, total nest count.

negligible number prior to 1903 to about 100,000 nesting pairs by the late 1950's. Fisher (1949) points out that the few censuses of albatrosses at Midway were made at different seasons and by different methods. A rough order of magnitude, however, is indicated (Figure 2).

Our estimates of the total nesting populations of Laysan and Black-footed albatrosses at Midway are based on sample nest counts of Laysan Albatrosses and complete nest counts of Black-footed Albatrosses. Counting could not always be accomplished soon after egg laying was completed; therefore, correction factors based on sample nest mortality studies are applied to the field counts.

Black-footed Albatross: In late January and early February of 1957, counts of all existing nests were made on Sand and Eastern islands and a

correction factor applied to obtain an estimate of the total nests in early December 1956, after egg laying had been completed. On Sand Island 3,659 nests were counted. From one small colony a correction factor of 17 per cent for nest mortality to this time was obtained, giving a calculated total of 4,281 nests. On 27 February our Eastern Island nest count of 1,669 nests was corrected to an estimated total of 2,286 nests in the early season. The 1957–1958 season counts indicated a possible increase (or an inadequate correction factor in the previous year) in nests on Sand Island, where 6,188 were counted between 2 and 5 December 1957, and a stable condition on Eastern Island, where a count of 2,333 nests was obtained on 9 December 1957.

Laysan Albatross: Available time did not permit us to attempt complete counts of the great number of nests of this species at Midway. Randomly distributed 0.0809 hectare (0.2 acre) circular plots were located by consecutively numbering grid-line intersections on a map, and selecting grid intersections from a table of random numbers. On Sand Island (area 384 hectares) 48 plots were counted; on Eastern Island (area 135 hectares), 28 plots.

In mid-December a total of 604 nests were counted on the 48 plots on Sand Island, and an estimate of 59,699 nests calculated. On Eastern Island, between 19 January and 16 February 1957, counts of all nests on 52 per cent of the nesting area were completed for a total of 14,024 nests. These counts were applied to the remaining area on the basis of similar nest density per unit area (as obtained from ground surveys and examination of aerial photographs) for a total estimate of 39,582 nests extant during the counting period. A nest mortality rate of 6 per cent per month was obtained from sample areas, giving a calculated total (corrected to early December) of 44,332 nests. The population on Sand Island was not estimated during the 1957–1958 season because widespread construction and earth-moving operations disrupted nesting activity. On Eastern Island sample plots were counted in December of 1957, giving a calculated total of 42,625 nests.

Counts obtained on Rocky and Seal islets in 1957 are given in Table 2.

After construction activities have been terminated at Midway Atoll, it will be necessary to conduct further population studies. Much land available for nesting during the period of our studies is now covered by blacktop and buildings.

Pearl and Hermes Reef (3). Five permanent islets and several semipermanent sandspits are surrounded by dangerous shallows and reefs. Vegetation is sparse and low, so that aerial photographs reveal all nesting albatrosses (Figure 3A). Wetmore visited this atoll in 1923 and gives the following estimates from his field notes (*in litt.*): Black-footed Albatross

Figure 3. The two nesting habitat types occupied by Laysan and Black-footed albatrosses: (A—top) Portion of North Island in Pearl and Hermes Reef, a low coral atoll in the western part of the Leeward Chain. Black-footed Albatrosses nest on the nearly bare sand immediately above the beach; Laysan Albatrosses occupy the grassy interior. Monk seals (*Monachus schauinslandi*) and green turtles (*Chelonia mydas*) lie on the beach. 18 December 1957. (B—bottom) Necker Island, a high rocky island in the eastern part of the Leeward Chain. A mixed colony of Laysan and Black-footed albatrosses occupies the moderately sloping summit areas. Annexation Peak, at the left, is 75 meters in altitude. 28 December 1957. (U.S. Navy photographs.)

—"Southeast Island, April 26: 1,000 pairs, in groups on sandspits and along the beach. Not found in the grass-grown interior. Middle (or Grass) Island, April 27: 800 pairs; Western (or Seal) Island, April 27: 1,200 pairs"; total: 3,000 pairs. Laysan Albatross—"Southeast Island, April 26: 300 pairs, middle one of the two western islands (which I called Grass Island) April 27: 100 pairs; westernmost island (which I called Seal Island) April 27: 150 pairs"; total: 550 pairs.

Aerial photographic surveys were made over all the islets at Pearl and Hermes Reef on 10 December 1956 and 18 December 1957. The results are presented in Table 2. To allow for unemployed birds, 25 per cent has been subtracted, and the figures rounded to two significant digits. There was no significant change between 1956–1957 and 1957–1958.

Wetmore's estimates were made in late season, after unknown mortality had taken place. It is evident, however, that both species have increased since 1923.

Lisianski Island (4). Munro (1942) visited Lisianski in 1891 and noted that "Laysan albatrosses were over the whole island but not so thickly placed as on Laysan." In 1904 and again in 1910 (Bryan, 1942) Japanese feather hunters slaughtered large numbers of birds on Lisianski. Rabbits, probably introduced during this period, had devoured all vegetation and precipitated their own extermination by the early 1920's. In 1923 the USS *Tanager* expedition found the vegetation beginning to recover. Wetmore's population estimates obtained on 16–19 May 1923 (*in litt.*) are: Black-footed Albatross, 1,000 pairs and Laysan Albatross, "not more than 800 pairs."

Now much of the island's surface is covered by bunchgrass (*Eragrostis* sp.), which appears to inhibit albatross nesting. The birds are able to walk among the tall grass clumps, but are unable to take off when surrounded by them. We saw several Laysan Albatrosses making futile attempts to take wing from fields of bunchgrass when frightened by our low-flying aircraft. If the habitat were ideal, the surface area of this atoll could accommodate a much greater Laysan Albatross population than it now does.

Aerial photographic surveys of Lisianski were conducted on 7 January 1957 and 28 December 1957. We counted 3,665 Black-foots during the 1956–1957 season survey. Allowing 25 per cent for unemployed birds, we estimated 2,749 nests. During the 1957–1958 survey, 3,490 birds were counted, for an estimated 2,618 nests.

A complete count of Laysan Albatrosses could not be made from the photographs because of brushy vegetation. By comparison with photographs of areas of known nesting density on Eastern Island, we estimated

approximately 161 nests per hectare, or a total of 29,141 nests on the island's 181 hectares; certainly a tremendous increase since 1923.

Laysan Island (5). In 1891 when Munro (1942) visited Laysan he found Captain George Freeth, Governor of the Island, operating a guano works there, and the island was covered with vegetation. Mules, pigs, rabbits, and guinea pigs were brought to the island by the guano diggers. Rabbits and guinea pigs were liberated about 1903 (Dill and Bryan, 1912). Having no enemies, they increased, particularly the rabbits, to tremendous numbers, so that by 1923 when Wetmore (1925) visited Laysan he found it a desert waste and the rabbits starving. Those remaining were killed. Twenty-three feather poachers arrived in May 1909, and were removed by the U.S. Revenue Cutter *Thetis* in January of 1910. Henshaw (1912), who visited Laysan in 1911, estimated that the poachers had killed "upwards of 300,000" Laysan Albatrosses and in all "not far from a million" sea birds. Dill and Bryan (1912) estimated in 1911 that one sixth of the original Laysan Albatross colony was left. Between 24 April and 5 June 1911 they measured areas covered by nesting colonies and computed that there were 180,000 nesting Laysan Albatrosses (90,000 nests) and 85,000 Black-footed Albatrosses (42,500 nests). Bailey (1952) considered this estimate "over liberal," since his careful nest count between 22 December 1912 and 11 March 1913 revealed only 12,312 Laysan Albatross nests and 7,722 of the Black-foot. Wetmore visited Laysan 9–13 April and 2–14 May 1923. He recorded (*in litt.*) "4,700 pairs of Black-footed Albatrosses. During a severe blow at the end of April all of the adults left the island, leaving the young to fend for themselves. On May 3 I noted a one-third decrease in the number of adults over those noted April 9–13." His estimate of Laysan Albatrosses was 6,800 pairs. Considering that Wetmore's estimates were made after considerable chick mortality had taken place, they tend to confirm Bailey's work. In 1951, from sample field counts, Brock (1951) computed 103,900 (51,950 nesting pairs) of Laysan Albatrosses and 18,240 (9,120 nesting pairs) of the Black-footed.

Our count of Black-footed Albatrosses on aerial photographs taken on 7 January 1957 revealed a total of 42,837 birds, or (subtracting 25 per cent for unemployed birds) 32,128 nests. On 28 December 1957, the total count was 44,697, and the estimated nests 33,523.

Laysan Albatrosses could not be completely enumerated on the aerial photographs taken on the same dates because of vegetation and excessive obliqueness of camera angle. The photographs of Laysan Island were compared with photographs of Eastern Island where the number of nests per unit area was known from ground counts. On Laysan it was estimated that 304 hectares (750 acres) were occupied by a nest density of 432 nests per hectare, giving a calculated total of 131,328 nests.

Between 27 May and 4 June 1958, 12 straight strip transects, 15.2 meters wide, were made between the lagoon and the ocean beach at nearly equal intervals around the island. We counted 2,884 Laysan Albatross chicks on 13.42 hectares of the island's 405 hectares (1,000 acres) of land area, for an estimated total of 87,036 chicks. Applying the nest mortality rate of 33 per cent, found on Eastern Island, Midway, we obtained a calculated total of 130,554 nests at the beginning of the nesting season. This estimate based on a ground count agrees very closely with the aerial photographic estimates made previously.

Gardner Pinnacles (6). Wetmore (*in litt.*) found two pairs of Laysan Albatrosses occupying Gardner Pinnacles on 22 May 1923. No Black-foots were noted.

On 28 December 1957 three Laysan Albatrosses were observed from the air, two on the pinnacle, one soaring nearby. Nesting could not be ascertained. The islet is too steep and tiny to accommodate more than a few pairs.

The *A.O.U. Check-list* (American Ornithologists' Union, 1957) includes Gardner Pinnacles in the breeding range of the Laysan Albatross, on the basis of Wetmore's observation. We have found no other published references to albatrosses on Gardner.

French Frigate Shoals (7). La Perouse Rock and 10 small coral sand islets compose this atoll. One of these, Tern Island, is completely taken up by an air strip and buildings of a U.S. Coast Guard Loran Station. In 1958, 13 men and a dog occupied Tern Island. During his visit, 22–26 June 1923, Wetmore (*in litt.*) recorded: Black-footed Albatross: "East Island, 75 well grown young; other islets, 330 well grown young. Only a few adults were still present to care for their young. Most of the juveniles were learning to fly and were on their own." Laysan Albatross: "East Island, 100 pairs; other islands, 30 pairs." On 18 and 19 December 1953 Dr. Frank Richardson (1954) visited the area. On Tern Island he found six nests with eggs of the Black-footed Albatross and 28 of the Laysan Albatross. His estimate of the number of nests with eggs on Trig, Skate, Whale, East, Gin, and Little Gin islands were: Black-footed Albatross, 1,500–1,700; Laysan Albatross, 600–700. He also visited La Perouse Pinnacle, but found no albatrosses nesting there.

We made a complete aerial survey of French Frigate Shoals on 28 December 1957. Our counts from aerial photographs, reduced by 25 per cent to allow for unemployed birds, and rounded to two significant digits, are presented in Table 2.

Wetmore's 1923 observations were made after the period of greatest chick mortality. Nevertheless, it would appear that a population increase has taken place at French Frigate Shoals since 1923.

Necker Island (8). In 1902 Dr. Gilbert "estimated roughly that there might be from one to two thousand" Laysan Albatrosses on the island, and the Black-footed Albatross was seen "sparingly" (Fisher, 1906). During a visit, 17–21 June 1923, Wetmore (*in litt.*) estimated "about 100 nearly grown young" of the Black-footed Albatross, "no adults present." Of Laysan Albatrosses he estimated 600 pairs. Richardson (1957) lists the Laysan Albatross as occurring there in fair numbers and the Black-footed in small numbers.

We made an aerial photographic survey of Necker (Figure 3B) on 28 December 1957. On the photographs we counted 3,327 Laysans and 491 Black-foots. Allowing 25 per cent for unemployed birds, we have estimated 2,495 and 368 nests of Laysans and Black-foots, respectively.

Nihoa (9). Also called Moku Manu or Bird Island. Bryan (1942) states that in 1923 a colony of Black-footed Albatrosses occupied the summit of the 285-meter high, dome-shaped plateau, and Richardson (1957) found the Laysan Albatross breeding there "in small numbers." Wetmore (*in litt.*), however, gives more specific data. In the period 10–16 June 1923 he found "60 well grown young [Black-footed Albatrosses] on a small flat below the pinnacle point of Miller's Peak (about 850 feet above the sea). Only 3 adult birds seen." He saw only two Laysan Albatrosses.

We made an aerial survey of Nihoa on 28 December 1957. A complete count could not be made from the photographs because of the shrubby vegetation that covers much of the steep slopes, and because of the possibility of confusing albatrosses with boobies (*Sula* sp.). A rough estimate of 500 Laysan and 50 Black-foot nests was made with 7 × 50 binoculars from the open hatch of the aircraft.

Kaula (10). The *A.O.U. Check-list* (American Ornithologists' Union, 1957) includes Kaula in the breeding range of the Black-footed Albatross on the basis of Wetmore's observations in 1923 (Wetmore, *in litt.*). We have found no other published references to albatrosses on Kaula.

We made an aerial survey of Kaula on 28 December 1957. Turbulent air currents prevented a close approach. The steep upper slopes are nearly bare; there appeared to be about 50 Black-footed Albatrosses on them.

Niihau (11). Nesting of Laysan Albatrosses on the island of Niihau was reported by Fisher (1951) in 1947, but no data on numbers were presented, as he was there during the late summer when the birds were absent. Aylmer F. Robinson (*in litt.*) of Makaweli, Kauai, one of the owners of Niihau, has generously furnished the following account of the history of the species on this island:

> The Laysan Albatross is not new to Niihau. The fact that it has a Hawaiian name (*Moli*) is in itself proof that the bird has been known to the Hawaiians since early

times. The only new feature is that the birds are present in greater numbers than heretofore, and that they now come every winter for nesting on the island, whereas formerly it was to a degree intermittent. This change took place largely during the war years [1940–1945] . . . .

The albatross nesting on the island are mostly on the sand dunes or flat sandy land above the sea-coast, although some nestings in volcanic ash areas have occurred. While most are on the north end of the island, some are scattered along the southerly coasts wherever the soft, sand conditions are right for nesting.

No attempt has been made to count the number of albatross nests in any season, and it would be difficult to do so as they are intermittent over miles of sand dune and beach areas, and under small trees and shrubs where protection from the weather can be had. However in years of heavy nesting they must run into at least several hundred of nests. There appears to be no difficulty in raising the young birds; [some of] the nests have been destroyed at the egg stage by wild pigs. Presumably however the greater part of the nestings are successful in raising their young. The birds come mostly in the late fall or early winter and leave in the early spring. They are present again this year [1957–1958], although whether in the same numbers as some years I have not yet had time to observe. Such protection as is possible has always been accorded to these birds by us, simply as a matter of interest in maintaining the varied bird life of the place.

The black or brown albatross [*D. nigripes*], although present in flight in the channel between Niihau and Kauai, I have not observed nesting on the island.

Our rough estimate of 500 nests (Table 2) is based on this information.

Moku Manu (12). The first known nesting of Laysan Albatrosses on Moku Manu, a small islet off the Mokapu Peninsula of the island of Oahu, occurred in the 1946–1947 season, when one pair successfully raised a chick. In the 1947–1948 season a deserted egg was found at the same site on 11 January 1948 (Fisher, 1948; Richardson and Fisher, 1950). One adult bird was seen on the islet in December 1955 (Hawaii Audubon Society, 1956), and three in December 1956 (Hawaii Audubon Society, 1957).

Johnston Island (13)

Both Laysan and Black-footed albatrosses formerly nested on Johnston Island (American Ornithologists' Union, 1957), but there is little historical record, and they were extirpated at an early date by feather hunters. On a visit, 10–18 July 1923, Wetmore (*in litt.*) found evidence of recent feather hunting on the island, but no albatross remains were found among the bones, indicating an early elimination of these species from the island. However, he did find "one young [Laysan Albatross] nearly ready to fly," indicating that this species was attempting to recolonize the island at that time. He found no Black-footed Albatrosses but states that "W. G. Anderson, a member of my party had been here in November 1922, and saw one bird with an egg." In April 1957 Moynihan (1957; and *in litt.*) found no albatrosses on Johnston Island; they are undoubtedly extirpated, as an airstrip now occupies almost the entire area of this small island.

Marshall Islands (14)

According to Dall (1874), the Black-footed Albatross was "said by Capt. Geo. Holder to nest on the coral island of Gaspar Rico, near the equator, in the winter season." This island is believed to be Taongi Atoll (also called Pokak), the northernmost of the Marshall Islands (Aldrich, *in litt.*), and is so listed in the *A.O.U. Check-list* (American Ornithologists' Union, 1957). Albatrosses have not been found there since that time. In 1952, Fosberg (*in litt.*) found no sign of albatrosses on the island.

Wake Island (15)

The following information on the history of albatrosses on Wake has been compiled by John W. Aldrich.

Titian R. Peale (1848: 290) describes the albatrosses found nesting on Wake Island on the 20th of December [1841] under the name *Diomedea brachyura* and called them 'short-tailed albatross.' . . . This description appears to refer to both the Black-footed and Laysan Albatrosses which he thought were different age plumages of the Short-tailed Albatross. On page 337 of this same report is listed a specimen of the albatross with number 745. U.S. National Museum specimen 15552 is a *Diomedea nigripes* marked Wake's Island, U.S. Exploring Expedition, field number 745. This is the only skin of either *nigripes* or *immutabilis* cataloged in the U.S. National Museum from the U.S. Exploring Expedition. Inquiry of the Philadelphia Academy of Natural Sciences determined that there were no specimens of albatrosses taken on Wake Island by this expedition in that institution.

In the egg collections of the U.S. National Museum is a single badly broken and patched albatross egg without any number, but marked on the shell *Diomedea brachyura,* Wakes I. Dec. 20, T. R. Peale. From its size and shape this egg appears to be that of the Laysan Albatross. It is smaller than the Black-footed Albatross eggs in the collection. In color it is indeterminable.

Dr. Alexander Wetmore (in conversation) tells of his visit to Wake Island, from July 27 to August 7, 1923. Wake Atoll is comprised of a large island and two smaller ones which consist of a mixture of large chunks of coral and sand, low in elevation so that storm waves occasionally sweep entire areas of land. Dense vegetation covers some areas, with some of tree size. Wetmore found evidence of extensive plume hunting operations by the Japanese. The buildings and equipment gave evidence of a fairly permanent and recently operated skinning plant. The pile of bird bones indicated great destruction of bird life over the years. The species identified from the bones were frigate birds, boobies, and terns (no albatrosses). The time of year, July 27 to August 7, when Wetmore was on Wake was the off-season for albatross nesting, so the lack . . . of living [albatrosses] might not have been significant. However, the lack of dead birds and bones would indicate that the species of albatross found on Wake by Peale must have disappeared before 1923, and the fact that they were not among recent bones left by plume hunters indicates extermination long before 1923.

Information supplied by several observers who were on Wake from 1935 until the Japanese occupation in 1942 confirmed the absence of albatrosses on the island during this period.

Oliver L. Austin, Jr. writes (*in litt.,* 28 July 1959) "I was unable to get any information on the Japanese experiences with the gooneys on Wake. Nothing on the

subject had found its way into the Japanese literature by 1951, and I was unable to find any Japanese who had been there." Yoshimaro Yamashina (*in litt.*, 17 August 1959) could not find anyone in Japan who had any knowledge of the former status of albatrosses on Wake I. Nagahisa Kuroda (*in litt.*, 27 March 1960), although conversant with activities of plume hunters on Marcus had no information on similar activities on Wake.

Thus the only concrete evidence that any species of albatross ever nested on Wake Island is the skin of the Black-footed and the egg of the Laysan Albatross in the U.S. National Museum, together with Peale's recognizable description of the birds he found nesting there. There is no evidence that the Short-tailed Albatross nested there.

It is probable that the Black-footed and Laysan albatrosses found nesting on Wake, by Peale in the early part of the 19th century, were completely wiped out by the Japanese feather-hunting industry which was very active in the North Pacific around the turn of the century and which has been well documented for Marcus Island by Kuroda (1954). As at Marcus the more desirable albatross feathers may have caused these species to be exterminated first, so that complete elimination of both Black-footed and Laysan albatrosses was accomplished at an early date. This probably accounts for the lack of albatross bones in the remains left by plume hunters, examined by Dr. Wetmore on Wake in 1923.

U.S. Navy personnel who visited Wake in 1957 and 1958 told us that albatrosses do not now occur on the island.

Marcus Island (16)

Both Laysan and Black-footed albatrosses nested on Marcus Island; the population was originally estimated to be at least 1,000,000 birds (Bryan, 1902; Namiye, 1905; Kuroda, 1954). They were extirpated by a feather-hunting company between 1896 and 1902 (Bryan, *op. cit.*). U.S. Navy Personnel who have visited Marcus in recent years have told us that there are no albatrosses present.

Seven Islands of Izu (17)

In the Izu Islands, Black-footed Albatrosses nested only on Tori Shima. According to Hattori (1889), who was on the island from April to July 1889, the Black-footed Albatross was less common than the Short-tailed Albatross; it nested near the shore and never mixed with the larger species. A colony of about 200 was found in April 1932, but only a few birds were present in April 1933 (Yamashina, 1942). The last Black-foots apparently were killed by feather hunters in 1933 (Austin, 1949). On 25 January 1955, Black-footed Albatrosses (number not stated) were found nesting on Tori Shima, indicating a reoccupation of the island (Ono, 1955). No later information is available.

Laysan Albatrosses colonized Tori Shima about 1918; by 1930 the population had built up to about 50, but decreased to only a couple of birds in 1933. All three species were extirpated in the latter year (Austin, 1949; Austin and Kuroda, 1953).

Bonin Islands (19)

In the Bonin Islands the occurrence and nesting of Black-footed Albatrosses on Muko Shima was recorded prior to 1930 (Seebohm, 1890; Momiyama, 1930; Okabe, 1930). No data on abundance are available. No albatrosses were present in the Bonin Islands in March and April 1949 (Austin, 1949; Austin and Kuroda, 1953).

Volcano Islands (22)

Black-footed Albatrosses were reported nesting in large numbers on Iwo Jima by Seebohm (1891). No information is available concerning their status in subsequent years. The species no longer occurs in the Volcano Islands (Austin and Kuroda, 1953).

DISCUSSION

About 560,000 Laysan Albatrosses and 110,000 Black-footed Albatrosses nest each year in the Hawaiian Archipelago. All adults do not nest every year. Under average rates of nesting failure, about 33 per cent of the pairs nesting during the 1956–1957 season failed to return the following year (Rice and Kenyon, ms). If we estimate 8.6 per cent for mortality of adult birds during the year (see below), this means that for every 67 nesting pairs there are 24.4 (33 minus 8.6) adult pairs that failed to nest that year. This indicates that the total number of adults is 36.4 per cent (24.4/67) greater than the number that nest in any given year. In other words, about 73 per cent (100/136.4) of the adults nest each year. Therefore, the total adult populations include about 760,000 Laysan Albatrosses and 150,000 Black-footed Albatrosses.

To determine the total population, including both nesting and nonnesting birds, additional estimates must be made for two categories of the population: (1) unemployed birds (this includes all birds that visit the breeding grounds at one time or other during the breeding season, but do not nest; included are many of the nonbreeding adults, as well as some innubile birds); and (2) innubile birds that remain at sea throughout the breeding season.

(1) *Unemployed birds.* We have data from two experiments to determine the ratio of unemployed birds to nesting birds. During the 1957–1958 season, a 40-hectare section of Sand Island, Midway Atoll, located between an aircraft runway and the beach, was selected by the Navy as an experimental control area. During the incubation period, 5,365 Laysan Albatross nests, representing 10,730 breeding birds, were counted in this area (see Methods). Between 15 January and 7 March 29,764 Laysan Albatrosses were killed on this area. Nearly all nesting birds were killed; about 100–400 (based on an estimate of 100–200 chicks that survived until June) escaped the kill. This means that at least 19,000 un-

TABLE 3

1956–1958 ESTIMATE OF LAYSAN AND BLACK-FOOTED ALBATROSSES ORIGINATING IN THE HAWAIIAN ARCHIPELAGO

	Laysan Albatrosses	*Black-footed Albatrosses*[1]
Adults nesting yearly	560,000	110,000
Unemployed birds	650,000–1,120,000	130,000–220,000
Innubile at sea[2]	130,000– 376,000	25,000– 74,000
Total	1,340,000–2,056,000	265,000–404,000
Rounded	1,300,000–2,100,000	260,000–400,000

[1] Studies of non-nesting population segments were made only for Laysan Albatrosses. To obtain a total population estimate it is assumed that the data may be applied to the Black-footed Albatrosses.

[2] One- and two-year-old birds only.

employed birds were killed. Very few unemployed birds remained in this area after the kill. Most unemployed birds are as firmly attached to a particular site as are nesting birds (Rice and Kenyon, ms). There was no decrease in the number of unemployed birds in areas contiguous to the experimental area. Other unemployed birds that utilized this area only earlier or later in the season may have escaped the kill. Therefore, the 19,000 birds that were killed represent the minimum number of unemployed birds in this population. This indicates a ratio of almost two unemployed birds to each nesting bird, if unemployed birds of all age classes are strictly attached to a particular area.

Another study of unemployed birds was conducted from 1 April to 16 June 1957. The purpose was to ascertain what fraction of the population of unemployed birds might be observed on shore at any particular time. An area of approximately 150 m^2, easily accessible to our living quarters, was selected. All unemployed birds found visiting it were captured; an identifying number was painted, with a pressure spray can, on the white breast of each bird. The study plot and surrounding area were checked two or three times daily, and all marked unemployed birds were recorded. Methods are described in Kenyon *et al.* (1958). A total of 68 birds was marked. These spent 436 bird-days, from a possible total of 3,128 bird-days, on or near the study plot, indicating that an average of about 14 per cent (or about 1/7) of the total of unemployed birds are on shore during any one day at this season. From sample counts it was ascertained that the average ratio of unemployed birds on the ground to incubating birds was 1 to 3.

Each incubating bird represents a breeding pair. If X equals the number of incubating birds, 2X equals the number of breeding birds. The number of unemployed birds may be calculated as 7X/3. This gives a ratio of unemployed birds to nesting birds of (7X/3) : (2X), or about 1.17 : 1 (Table 3).

(2) *Innubile birds at sea.* Little quantitive data are available to indi-

cate the number of innubile birds that remain at sea. We know neither the proportion of each age group that returns to the islands, nor the mortality rates during the first few years at sea. A large-scale banding program (Rice and Kenyon, ms) has indicated that no appreciable number of innubile birds return until at least the third season following hatching. This means that at least the two youngest age groups are unrepresented in the census figures.

In the 1938–1939 season Hadden banded 127 adult Laysan Albatrosses on Sand Island, adjacent to Pan American Airlines' Gooneyville Lodge. During the 1956–1957 and 1957–1958 seasons we examined all birds on this area several times during the incubation period. At least 25 of these original banded birds were still alive during the 1956–1957 season. Therefore, the mean annual mortality was not greater than 8.6 per cent. If the population is stable or increasing, each year an average of at least 17.2 per cent of the breeding pairs must produce a young bird that survives to breeding age. Since only 73 per cent of the adult birds nest each year (see above), at least 23.6 per cent (17.2/0.73) of the eggs must produce birds that survive to breeding age. Survival of young Laysan and Black-footed albatrosses from egg laying to fledging on Sand and Eastern islands varied from 42 to 67 per cent (Rice, 1959). Therefore, the size of the one- and two-year age groups probably lies between 23.6 and 67 per cent of the number of eggs laid annually—or between 47.2 and 134 per cent for the two age groups combined.

These population estimates have been summarized in Table 3. We consider the lower figure an absolute minimum; the upper figure may be too low, because we have made no allowance for any unknown per cent of the birds older than two years that fail to visit the island during the breeding season.

The above data indicate that the total population of albatrosses is at least three times the number nesting during any one season. World populations may be conservatively estimated at 1,500,000 Laysan Albatrosses and 300,000 Black-footed Albatrosses.

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supplied unpublished information on the status of albatrosses on several islands.

SUMMARY

Laysan and Black-footed albatrosses formerly nested on 19 islands and atolls in the central and western North Pacific Ocean between 14° and 31° N latitude. Many breeding colonies were extirpated, chiefly by feather hunters, during the latter half of the 19th century. The two species now breed on only 11 islands and atolls of the Hawaiian Archipelago (except for a few Black-footed Albatrosses on Tori Shima in the Izu Islands). During the 1956–1957 and 1957–1958 seasons there were 280,000 nesting pairs of Laysan, and 55,000 nesting pairs of Black-footed albatrosses, in the Hawaiian Islands. Computations derived from data on the Laysan Albatross (and presumed to be applicable to the Black-foot also) indicate that 73 per cent of the adult pairs are believed to nest each year; therefore, the total number of adult pairs is estimated at 380,000 Laysan and 75,000 Black-footed albatrosses. On the breeding grounds unemployed birds (nonbreeding adults and innubiles) outnumber nesting birds by a ratio of 1.17 : 1 to 2 : 1. Mean annual mortality among 127 adult Laysan Albatrosses during 18 years was not greater than 8.6 per cent. One- and two-year-old birds were not found on the breeding grounds. The world populations are conservatively estimated at 1,500,000 Laysan Albatrosses and 300,000 Black-footed Albatrosses.

The Short-tailed Albatross, which formerly nested on perhaps nine islands in the western North Pacific, was reduced to 18 nesting pairs, all on Tori Shima, in the 1958–1959 nesting season (Fauna Preservation Society, 1960).

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THE APPLICATION OF SOME SPECIAL IMMUNOLOGICAL METHODS TO MARINE POPULATION PROBLEMS*

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The recognition of characteristics which distinguish populations of marine organisms is important for the solution of problems of conservation and management, and for better understanding of problems in biology and evolution. Because of this importance, and basic interest in comparative immunogenetics, there have been a considerable number of investigations directed at the application of immunogenetic methods to marine population problems in the past several years.

Numerous advances have been made in recent years in the study of marine populations by immunogenetic methods. Many of these have resulted from the application of saline agglutinin and precipitin tests. However, in addition, specialized immunological methods are available which either have been, or could be applied profitably to studies on marine organisms.

Most of those to be discussed were not developed specifically for the solution of marine population problems but the need for them in such research is readily apparent. In this laboratory we have found that it is rewarding to utilize these newer methods for detecting variations in soluble antigens, and to take advantage of what Landsteiner (1945) called "immunological perspective," that is, the greater specificity obtained when antisera are produced in animals closely related to those whose antigens are being studied.

IMMUNODIFFUSION METHODS FOR THE STUDY OF SOLUBLE ANTIGENS

Important modern techniques for the study of soluble antigens are those of immunodiffusion. The technique which has had greatest application to biological problems is the double diffusion method of Ouchterlony (1958) which consists of allowing both antigens and antibodies to diffuse toward each other from wells through a thin layer of semi-solid agar contained in a petri dish. This method results in the formation of lines of precipitate at the position in the medium where an antigen meets its specific antibody in optimal proportions. Since the position of the lines is dependent upon the diffusion rates of the antigen and antibody and on their relative concentrations, separate lines may be formed for each antigen and antibody system. The chief advantage of this method is that it allows side-by-side comparisons of antigenic mixtures or of antisera so that the qualitative identity or

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relationships of their components may be determined directly. This method has recently been very extensively applied to immunogenetic studies of soluble antigens. Semi-micro and micro modifications of this method have been developed. The first uses a thin layer of semi-solid agar on a microscope slide as the supporting medium and requires only about 0.02 ml of serum. The micro method utilizes a cellulose-acetate film strip for the supporting medium and requires only about 0.001 to 0.002 ml of serum (Consdon and Kohn, 1959).

The Ouchterlony method was used by Bargetzi (1958) in a taxonomic study of two species of Neuchatel Lake whitefish. We have used the method to distinguish differences correlated with area of origin and with sex in studies of red salmon serum (Ridgway, Klontz, and Matsumoto, 1961). An example of the latter is shown in figure 1. We have also used this method

FIGURE 1. Micro-immunodiffusion test for an antigen detectable in the sera of maturing female salmon. Specific antiserum in center well. Sera of maturing female salmon in wells 1, 2, 4, and 6. Serum from an immature female salmon in well 3. Serum from a male salmon in well 5.

to distinguish differences between species of salmon (Klontz and Ridgway, 1962), and to distinguish differences between species of tuna (Ridgway, 1961a). Suzuki and Morio (1959) have also demonstrated that this method can be used to distinguish species of tuna.

A third method for the study of soluble antigens is that of immunoelectrophoresis. This method, which separates the antigenic materials in one direction by electrophoresis and in the other by double diffusion precipitin analysis with specific antisera, was developed by Grabar and Williams (1953). It is a very useful advance in methodology available for the study

of genetically controlled differences in the soluble antigens of marine organisms and has been applied to fish sera by Bargetzi (1958) and by Fine and Drilhon (1960). In our laboratory Dr. Kathryn K. Krauel and I are applying Scheidegger's (1955) micro-modification of this method to the study of antigenic differences between salmon. Figure 2 shows the results of an immunoelectrophoretic analysis of sockeye salmon serum.

FIGURE 2. Immunoelectrophoresis of red salmon (*O. nerka*) serum. The serum from a red salmon was placed in small holes in the agar and subjected to electrophoresis. Then longitudinal ditches were cut in agar and filled with antisera. This resulted in separate arcs of specific precipitate for different antigen-antibody systems. The specificities of three rabbit anti-red-salmon sera are compared.

THE USE OF FISH FOR THE PRODUCTION OF ANTIBODIES

Among the methods available for the study of differences in cellular antigens of fish is the use of fish themselves as the antibody producer. As pointed out earlier, we need to take Landsteiner's advice and use animals which are closely related to the animal under study, for the production of antibodies in order to take advantage of their better "immunological perspective." Especially important is the use of another member of the same species (isoimmunization) for the production of blood typing antibodies. Isoimmune sera usually detect more numerous and finer differences in blood group antigens. In the balance of this paper I will discuss some of the experiments we have conducted on the production of hemagglutinating antibodies in fish.

Since it is known that the rate of antibody production by cold-blooded vertebrates is dependent on the temperature at which they are held (Hildemann, 1962), this is an important factor to consider when attempting to immunize fish. Much of the work which has been done in this field has tended to indicate that not only is the rate of antibody production slower at colder temperatures but that there may be some minimum temperature below which antibody production stops. For example, in our work on trout and salmon all attempts to produce isoimmune antibodies in fish held at 3° to 5°C. were unsuccessful, while we were able to produce isoagglutinins in red

salmon (*Oncorhynchus nerka*) held at 9° to 14°C. and in rainbow trout (*Salmo gairdnerii*) held at 15°C. (Ridgway, 1961b). The minimum temperature at which antibody production by fish has been reported in the literature is 10°C. (Smith, 1940). This raises the question whether antibody production occurs at all in those fishes which normally live in very cold waters. In table 1 data are presented on some experimental immunizations of sablefish (*Anoplopoma fimbria*) which show that cold water fishes do produce antibodies at significant rates at temperatures below 10°C.

TABLE 1.

Production of hemagglutinating antibodies by sablefish (*Anoplopoma fimbria*) at temperatures below 10 °C.

Fish No.	Antigen	Duration of immunization	No. of inoculations	Temperature	Titer
3	Silver salmon* RBC's	78 days	12	5°–8°C.	1:246
6	"	50 days	11	5°–7°C.	1:32
7	"	42 days	9	5°–7°C.	1:8
8	"	27 days	7	5°–6°C.	1:8
9	"	42 days	9	5°–6°C.	1:2
11	Steelhead† RBC's	33 days	9	6°–8°C.	1:2
12	"	33 days	9	6°–8°C.	1:2

Control bleedings taken before immunization contained no antibodies for silver salmon or steelhead red blood cells.

**Oncorhynchus kisutch.*

†Salmo gairdnerii,

Even more revealing is the case of one sablefish which was immunized with nine inoculations of herring red blood cells over a period of 55 days during the spring. The water temperature ranged from 9° to 11°C. during this period and the fish produced hemagglutinating antibodies which reacted to a dilution of 1 to 320. This titer was maintained throughout the summer months without further inoculations. After the subsequent winter during which the temperature of the water remained below 10°C. (from 6° to 9°C.) for a period of five months the fish was bled again without being reinoculated. To our surprise we found that the hemagglutinating titer for herring red cells had risen to 1 : 8000, a higher titer than we have ever produced in rabbits. This and other sablefish antisera have been useful in detecting blood types in Pacific herring (*Clupea harengus pallasi*) (Ridgway, 1958). Thus it seems apparent, even though warm water fishes have a faster rate of antibody production, that with a little patience the study of cold water species can also be rewarding.

As mentioned earlier, isoimmunization is by far the most discriminating and productive method of detecting blood type differences in animals. Isoimmunization of fishes was first carried out by Hildemann (1956, 1958) who demonstrated marked heterogeneity in the erythrocyte antigens of goldfish. We have produced isoimmune hemagglutinating antisera in red salmon and

rainbow trout (Ridgway and Klontz, 1960; Ridgway, 1961b). The results of tests with these sera indicate that there is considerable antigenic heterogeneity in these species also.

Although some of our trout isoimmune sera had titers as high as 1 : 128 when first taken, the titers dropped markedly on storage at −35°C. We found that the most convenient and consistent method of testing these sera is by the capillary agglutination method of Chown and Lewis (1946).

Our most important observation with rainbow trout isoimmune sera is that most of them also detect individual differences in the species of Pacific salmon. Thus, just as cattle isoimmune sera have been useful in studies of blood groups in American bison (Owen, Stormont and Irwin, 1958) and in sheep (Stormont, Suzuki and Rasmusen, 1957), studies on isoimmune antibodies produced in readily available species of fish can prove to be useful in demonstrating blood types in other related species.

SUMMARY

Among the special immunological methods which have been profitably applied to marine population problems are immunodiffusion methods for the study of soluble antigens and the use of fish as antibody producers.

Evidence is presented that cold water fishes produce antibody at significant rates below 10°C. indicating that they can be used profitably for immunization and isoimmunization.

Isoimmune sera produced in trout have been used to detect individual differences in species of Pacific salmon.

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DEMONSTRATION OF BLOOD GROUPS IN TROUT AND SALMON BY ISOIMMUNIZATION

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An increasing number of investigators have conducted studies on blood groups of fishes in the past few years, in order to solve various problems involved in the study and management of populations of economically important fishes, provide a sound basis for possible selective breeding programs in fish hatcheries, and answer interesting and basic questions in comparative genetics and immunology.

Natural isoagglutinins have been found in a few cases (J. E. Cushing and G. L. Durall, 1957), and several blood group differences have been demonstrated with a variety of normal sera and immune sera prepared in rabbits (see G. J. Ridgway and G. W. Klontz, 1960, and C. J. Sindermann and D. F. Mairs, 1960, for examples and reviews of pertinent literature).

However, in order to attack the problems of fish blood groups in any considerable depth, it is evident from the work on other animals (C. Stormont, R. D. Owen, and M. R. Irwin, 1951; W. E. Briles, C. P. Allen, and T. W. Millen, 1957; C. Cohen, 1960) that one must turn to isoimmunization.

The size of certain economically important fish species or the difficulties involved in culturing and maintaining them will limit the number on which one can expect to conduct isoimmunization experiments. This makes it doubly important that isoimmunization programs be carried out on those species which are large enough, and which can be cultured and maintained.

Successful production of isoimmune hemagglutinins in goldfish has been reported by W. H. Hildemann (1956, 1958), and in red salmon (*Oncorhynchus nerka*, Walbaum) by G. J. Ridgway and G. W. Klontz (1960).

This report will describe some of the results of our studies on isoimmunization of rainbow trout (*Salmo gairdnerii*, Walbaum) and red salmon. A more complete report of our work on isoimmunization of trout is in preparation (Ridgway *et al.*, 1961). I acknowledge the extensive part which Klontz and Smith have taken in these studies.

Experimental

We have isoimmunized a total of 140 red salmon and 156 rainbow trout. Fifteen of the red salmon and 27 of the rainbow trout have produced detectable hemagglutinins. Disease conditions and accidents involving interruption or contamination of the water supplies caused losses of about half of those not producing antibodies after at least one bleeding but before they had completed very extensive isoimmunization programs. If we discount these losses it appears that we were about 20 per cent successful with red salmon and about 35 per cent successful with rainbow trout in the production of isoimmune antisera. Some of the properties of these antisera and some of the factors influencing their successful production will be considered.

Factors Involved in Isoimmunization of Salmon and Trout

Since the rate of antibody production in fishes is markedly influenced by temperature (J. E. Cushing, 1942; W. H. Hildemann, 1957), this factor must be taken into consideration.

We were able to produce low titer isoimmune antibodies in red salmon held at 9° to 14° C., but unable to produce isoimmune antibodies in relatively limited trials on red salmon and rainbow trout held at 3° to 5° C. All our successful attempts to produce isoimmune sera in rainbow trout were made on fish held in a water supply of constant 15° C. temperature. The saline agglutinin titers of these sera range from 1:2 to 1:64 while control bleedings taken before immunization never contained natural isoagglutinins. The use of water temperatures very much above 15° C. are not practical for salmonid fishes because of disease problems.

The more consistent and potent production of isoimmune hemagglutinins in goldfish demonstrated by Hildemann (1956, 1958) may be due in part to the higher temperature (23° C.) at which they were held. However, a comparative study of isoimmunization involving several species of both warm and cold water fishes is needed to determine the variability between species not associated with temperature.

We have used both intracardial and intraperitoneal injection routes, but have settled on the intraperitoneal route since it is equally effective and much less likely to result in loss of the fish. Peculiarities of fish anatomy render intravenous and intramuscular injections impractical. All bleedings were made by cardiac puncture. The fish were anesthetized with 1:20,000 tricaine methane sulfonate* before either being bled or injected.

We have tried several doses and courses of injection including 3 injections per week of 0.2 ml. to 0.5 ml. of whole blood for a three-week period. Taking into account the problem of losses of fish due to handling, we have decided that a course of six weekly injections of 0.2 ml. whole blood is the most efficient for our purposes. If detectable agglutinins have not been produced within a month after the sixth injection a second course of three weekly injections are given. Most of the fish have required at least 2 to 3 months to produce detectable isoagglutinins. One tenth to 0.2 ml. of whole blood appears to be as effective an antigen dose as larger amounts.

Injecting 0.1 ml. of a 2 per cent suspension of heat killed *Mycobacterium tuberculosis* BCG strain simultaneously did not increase the number of individuals producing isohemagglutinins.

The recipients in all our trout isoimmunizations were from a single population. Donors were either selected at random from the same population or from three different populations, or were individuals known to possess an antigen not possessed by the recipient. The proportion of individuals producing detectable antibodies did not differ markedly between these separate groups, indicating that in trout as in other animals (Cohen, 1960) factors possibly genetic in nature, other than antigenic incompatability influence the success of isoimmunization.

* MS222 Sandoz Pharmaceuticals, Hanover, N.J.

Properties of Isoimmune Antisera Produced in Trout

The isoimmune sera we have produced in trout are similar in their properties to isoimmune sera produced in some of the more familiar animals. They are non-hemolytic for trout cells. This is not due to lack of complement, the presence of which can be demonstrated with natural hemolysins for rabbit cells. They contain saline agglutinins with titers ranging from 1:2 to 1:64. Several with low saline agglutinin titers have markedly higher titers when diluted

TABLE 1
COMPARISON OF SALINE AND SERUM DILUTION TITERS OF SEVERAL TROUT ISOIMMUNE SERA

Serum	Titer	
	In saline dilution	In serum dilution
I-9-1 (1-7-57)	2	8
I-9-1 (1-21-57)	2	16
I-9-1 (1-6-58)	8	128
I-9-1 (1-20-58)	8	32
J-6-2 (1-7-57)	4	32

TABLE 2
ABSORPTION ANALYSIS OF A TROUT ISOIMMUNE SERUM

Serum I-2-1	Test cells						
	2	3	5	6	7	9	10
Unabsorbed	4	0	0	4	3	1	1
Absorbing cells:							
2	0			0	0	0	0
6	0			0	0	0	0
7	1			3	0	0	0
9	3			1	3	0	0
10	3			3	3	0	0

Absorption dilution 1:5 Test dilution 1:10

with normal trout serum, indicating the presence of incomplete antibodies. Some examples are presented in TABLE 1.

Most of the relatively high titer trout isoimmune sera possessed antibodies of more than one specificity. An absorption experiment demonstrating this is presented in TABLE 2. There are four antigenic types demonstrated with one serum in this experiment. Individuals 3 and 5 are the nonreactive "O" type; the donor numbers 2 and 6 possess all the antigens detected by the serum; number 7 possesses part of these antigens, and numbers 9 and 10 a lesser fraction of them.

Our evidence indicates that the degree of antigenic diversity in rainbow trout must be considerable. When tested with a large enough panel of cells,

most of our antisera displayed differences in specificity, even though the donors and recipients were picked for incompatability with a given serum. A comparison of the specificities of three such sera is made in TABLE 3. All possible combinations of reactions are represented.

TABLE 3
COMPARISON OF SPECIFICITIES OF THREE RAINBOW TROUT ISOIMMUNE SERA

Reactions	Number reacting
(−) with all 3 sera	9
(+) with all three sera	3
(+) with 91 + 96 (−) with 101	9
(+) with 91 + 101 (−) with 96	2
+ with 96 + 101 − with 91	10
+ with 91 − with 96 + 101	2
+ with 96 − with 91 + 101	25
+ with 101 − with 91 + 96	1
Total	60

TABLE 4
GENETIC RATIOS OBTAINED ON TESTING SIBLING GROUPS OF RAINBOW TROUT WITH ISOIMMUNE SERA

Group	Parents reaction with serum 91	Serum		
		91	96	101
		(Number +/Number −)		
1	− × −	0/26	24/6	14/12
2	+ × +	23/6	27/3	—
3	− × −	0/30	25/5	—
4	− × +	20/10	28/2	—

There is no statistical association between the reactions obtained with th three sera indicating that the antigens detected by each are probably controlle by separate genetic systems.

Tests on several sets of full siblings with these three sera produced th genetic ratios in TABLE 4. Some of these ratios indicate that the individua sera are detecting more than one antigen. Unfortunately, a more precis analysis of the genetic systems with absorbed sera has not been possible, a

yet, because of the short supply of antisera. Nevertheless, it is evident that rainbow trout have blood group antigens which are subject to genetic analysis and which are segregating within Mendelian populations.

Summary

The existence of blood groups in rainbow trout (*Salmo gairdnerii*, Walbaum) and red salmon (*Oncorhynchus nerka*, Walbaum) has been established through the production of isoimmune hemagglutinins.

The percentage success in producing detectable isoimmune antibodies is quite low in both species.

The influences of such factors as water temperature (body temperature of the fish), route and course of immunization, antigen dose, use of adjuvants, and known antigenic incompatability were considered. Water temperatures between 10° C. and 15° C. are considered essential for efficient production of isoimmune sera in these species. Weekly intraperitoneal injections of 0.1 ml. of citrated whole blood for a period of six weeks or more, without the addition of adjuvants, is considered to be the procedure of choice.

Even when the most efficient methods were used, and the donor and recipient were incompatible for a known antigen, the likelihood of successful production of isoimmune sera was small. This is considered to indicate that additional factors, probably genetic in nature, are involved in the production of isoimmune antibodies by trout.

The isoimmune sera produced have saline agglutinin titers ranging from 1:2 to 1:64, and some have higher titers when diluted with normal trout serum. The sera are not hemolytic with trout complement and frequently possess more than one specific type of antibody.

The evidence presented indicates that there is considerable antigenic diversity among rainbow trout, and that a number of antigenic types are segregating in trout populations.

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INTRASPECIFIC DIFFERENCES IN SERUM ANTIGENS OF RED SALMON DEMONSTRATED BY IMMUNOCHEMICAL METHODS

by
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ABSTRACT

The sera of most Alaskan red salmon (*Oncorhynchus nerka* Walbaum) were found to contain at least 14 antigenic components when tested by the double diffusion precipitin analysis method of Ouchterlony with antisera prepared in rabbits. Two of these components, designated antigens I and II, were missing from 116 of 126 blood samples from red salmon taken in Asian waters. In contrast, only 31 of 905 blood samples from red salmon of American origin lacked these components. Intermediate frequencies of occurrence of these antigenic components were found in blood samples from red salmon caught in the central North Pacific and Bering Sea. The results are considered indicative of the intermingling of Asian and American stocks of red salmon in these areas.

An additional antigen (or antigens) was found which occurs in the sera of only mature or maturing female red salmon.

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INTRODUCTION

As part of the research program of the International North Pacific Fisheries Commission, serological or immunochemical methods have been applied to the problem of distinguishing geographic races of Pacific salmon. Research directed toward discovering differences in cellular antigens has been described in two previous reports (Ridgway, Cushing, and Durall, 1958) and (Ridgway and Klontz, 1960). The application of such differences in cellular antigens to populations sampled on the high seas has been hampered because of the difficulty of obtaining, preserving, and transporting fresh whole blood from fish caught in Asian and high-seas areas without hemolyzing the cells. Consequently, an extensive search was made for intraspecific differences in the soluble antigens present in serum. It was considered that if such antigenic differences were present, they would probably be detectable in the samples of whole frozen blood available when one of the modern immunochemical methods of diffusion precipitin analysis was used.

This paper will report on research which led to the discovery of such intraspecific differences in soluble blood antigens of red salmon (*Oncorhynchus nerka* Walbaum) and which has been applied to the problem of distinguishing the continental origin of red salmon taken on the high seas.

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REVIEW OF LITERATURE

Rapid developments have been made in the past few years in the study of intraspecific differences in soluble antigens, and the inclusion here of a short review of pertinent literature is considered essential.

The extent of intraspecific antigenic heterogeneity discovered in serum components of man and other animals is considerably less than that in cellular antigens. Until recently, differences in soluble blood-

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group substances were the only intraspecific differences in soluble antigens known to occur. In man, the presence or absence of soluble substances in saliva and serum, corresponding in specificity to the major blood-group antigens of the individual, were found to be controlled by a pair of allelic genes called the secretor and nonsecretor genes (Schiff and Sasaki, 1932). Subsequently, other genetically controlled factors known as the Lewis factors were found to be involved in the specificity of these substances (Grubb and Morgan, 1949). A soluble, serologically reactive substance known as the J-substance was found to be present in the sera of some cattle (as well as on the erythrocytes of some) and its presence or absence was demonstrated to be under genetic control (Stormont, 1949 ; Stone and Irwin, 1954).

In addition to such differences in soluble blood-group substances, recent studies have demonstrated the existence of intraspecific heterogeneity in the serum or milk proteins of some of the better-studied domestic animals and of man. In some cases, this heterogeneity has been demonstrated serologically and, in others, through the use of electrophoresis.

The occurrence of genetically controlled differences in the beta-lactoglobulins of cow's milk has been reported by Aschaffenburg and Drewry (1955). Paper electrophoresis of the fraction of their milk soluble in 20-percent sodium sulfate showed that cows had either or both of two beta-lactoglobulins. Blumberg and Tombs (1958) compared the frequencies of the beta-lactoglobulin types of Nigerian and Icelandic cattle with those of British cattle and found the frequencies did not differ significantly among populations. These authors also found polymorphism in the alpha-lactalbumins of Nigerian cattle by paper electrophoresis. Some Nigerian cattle had a single alpha-lactalbumin with the same mobility as that in British cattle ; others had two alpha-lactalbumins, one with a higher mobility than the other. British and Icelandic cattle lacked this more-mobile alpha-lactalbumin.

The existence of six electrophoretically different phenotypes in the serum beta-globulins of cattle and evidence for genetic control of these characters were described by Ashton (1957, 1959). Ashton (1958) also presented evidence for the existence of eight phenotypes in the beta-globulins of sheep. Smithies and Walker (1955) found differences in the beta-globulins of humans by starch gel electrophoresis and demonstrated the differences were genetically controlled. Sutton *et al.* (1956) demonstrated significant differences in the frequencies of these characters between Caucasians and Africans. Thompson *et al.* (1954) studied the sera of seven strains of mice and found that one contained a distinct, genetically controlled beta-globulin.

Different genetically controlled serological types of human gamma-globulin were demonstrated by Grubb and Laurell (1956), and differences in the frequencies of these types were found between the Swedes and Eskimos.

Oudin (1956), using immune isoprecipitins induced by injecting rabbit immune precipitates incorporated in Freund's adjuvant, found serological differences between the gamma-globulins of individual rabbits. The differences were demonstrated by Oudin's (1946, 1952) method of agar diffusion precipitin analysis. Dray and Young (1958, 1959) confirmed the findings of Oudin and extended the observations to differences in other antigenic components. They induced immune isoprecipitins by the injection of whole serum in adjuvants and conducted tests by agar diffusion, immuno-electrophoresis, and passive cutaneous anaphylaxis. Differences were found in components with the mobilities of alpha-, beta-, and gamma-globulins. The extent of heterogeneity was sufficient to allow separation of 90 rabbits into 30 groups. Another example of a genetically controlled intraspecific difference in serum proteins is the hereditary disease of man, congenital agamma-globulinemia, which was first reported by Bruton (1952). It is apparent that ample evidence exists for intraspecific differences among the serum antigens of the better-studied vertebrate animals.

There have been only a few previous reports of the serological distinction of lower taxonomic units of fish based on differences in serum antigens. Taliev (1941, 1946) found serological differences between races of *Coregonus autumnalis migratorius* (Georgi) and forms of wild and domesticated carp (*Cyprinus carpio* L.). Bargetzi (1958), using the agar diffusion technique of Ouchterlony, found some differences between the sera of two forms of Neuchatel Lake coregonids *Coregonus fera* Jurine and *Coregonus macrophthalmus* Nüsslin.

Intraspecific differences in the soluble antigens of micro-organisms have been known for a long time. For example, Tempel (1957) used the Ouchterlony method of agar gel diffusion to demonstrate serological differences between physiological races of *Fusarium oxysporum*. Many additional studies of intraspecific differences in the soluble antigens of micro-organisms could be cited.

METHODS

CHTERLONY METHOD OF DOUBLE DIFFUSION PRECIPITIN ANALYSIS IN AGAR

modification of Ouchterlony's (1949) method of ›le diffusion precipitin analysis in agar has been throughout the course of this work. Since this ›od is somewhat specialized, a brief and diagram- c description of it and its theoretical basis is pre- ed. The interested reader will find additional riptions and discussions of this method in the ers of Ouchterlony (1949, 1953a, 1953b) ; Oudin 2) ; Wodehouse (1956) ; and Feinberg (1957).

he method consists of allowing the antigen solu- s and the antiserum to diffuse from small cups ard each other through a thin layer of semisolid medium that contains saline, buffer, and a pre- ative. As the components diffuse from their cups ›ugh the agar medium, opposing gradients in their centrations are formed. Along some perpendicu- line, between the antigen and antibody wells, the gen molecules encounter their specific antibody ecules in an optimal proportion of concentrations precipitation occurs. After a given period of usion, the position of this line of precipitation for h antigen-antibody system is dependent on the ial concentrations of the particular antigen in the ›tion being tested, the diffusion rate of the antigen, l the concentration of the specific antibody in the iserum being used. Since each of these factors vary between antigen-antibody systems, separate s can be formed for each antigen-antibody system sent.

The precipitation reaction is most easily understood erms of Marrack's (1938) lattice theory of antigen- ibody reactions. According to this theory (pre- ted diagrammatically in Figure 1) and a consider- e amount of immunochemical evidence, the an- ens and antibodies that participate in precipitation ctions are multivalent ; that is, they possess more n one reaction site. Present evidence indicates t antibodies possess two reaction sites while antigens sess two or more, frequently many. The reaction ween a soluble antigen and its specific antibody is ›ught to occur in two stages. The primary reaction a rapid molecular interaction which results in the mation of relatively small complexes. The second- reaction, which occurs when the ratio of antigen d antibody concentration is optimal, is a slow inter- ion of the primary complexes to form insoluble gregates.

One of the advantages of the Ouchterlony method

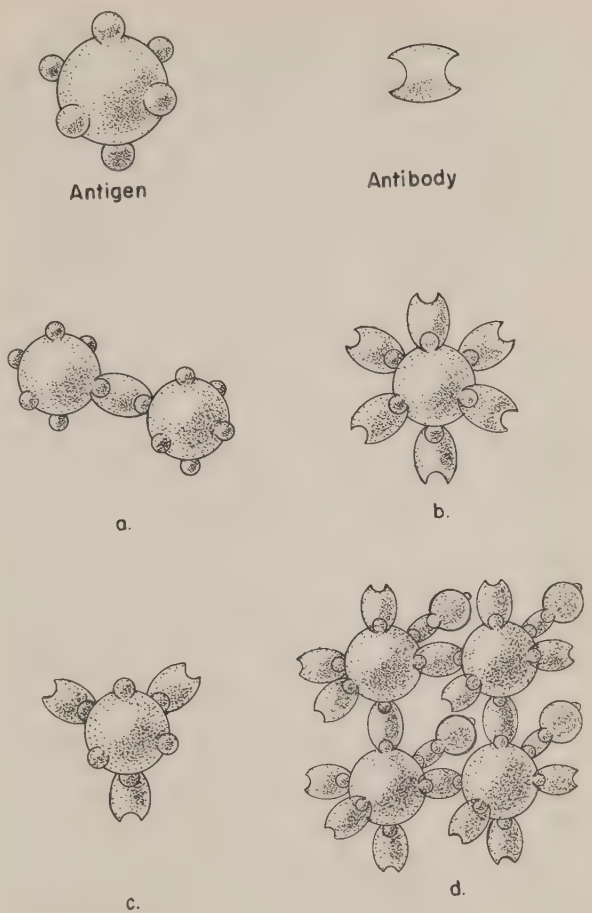

FIGURE 1. Diagrammatic representation of the lattice theory of antigen-antibody reactions. a. Soluble primary aggregate formed in excess antigen. b. Primary aggregate formed in excess antibody. c. Primary aggregate formed at zone of optimal proportions. d. Insoluble lattice formed by interaction of the primary aggregates shown in c.

is that the antigens present in different samples of known or unknown antigenic composition can be compared directly. The samples to be compared are placed in adjacent cups equidistant from the antiserum cup. The types of comparative reactions as demonstrated by Ouchterlony are illustrated in Figure 2. Identical antigens from the two samples form lines which fuse (Fig. 2a). If antigens are related but not identical the lines partially fuse resulting in the formation of a "spur" (Fig. 2b). Unrelated antigens diffusing from adjacent cups form lines which cross (Fig. 2c). Finally, if no antibodies in the antiserum are directed against the antigens in a particular sample, no lines form (Fig. 2d, right well).

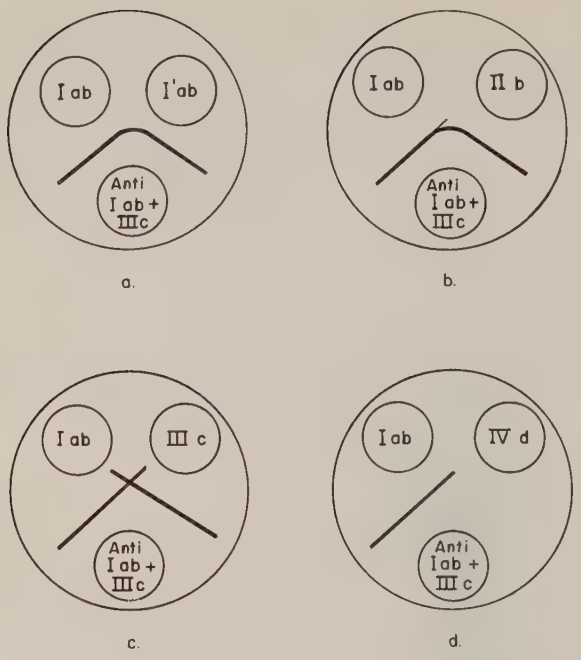

FIGURE 2. Types of comparative reactions in agar-plate diffusion method of precipitin analysis. a. Reaction of identity, complete fusion of line. b. Reaction of partial identity, "spur" formation or partial fusion of line. c. Reaction of nonidentity, crossing of lines. d. Lack of reaction, absence of lines.

Another advantage of the agar-diffusion method is that it frequently allows study of the reactions of individual antigens present in complex mixtures without resort to difficult and time-consuming absorptions, because of the separation of the individual reactions (lines) in the space between the antigen and antibody cups, as pointed out previously. With very complex mixtures, preliminary absorption may still be necessary but can frequently be carried out by the simple method of inhibition or intragel absorption first described by Björklund (1952).

Medium Used

The diffusion medium consisted of Difco agar, 1.5 ; sodium chloride, 0.72 ; tri-sodium citrate dihydrate, 0.6 ; merthiolate Lilly, 0.01 ; trypan blue, 0.01 ; distilled water, 100. The pH of the medium was adjusted to 6.7 with hydrochloric acid. Citrate was used as the buffer to prevent precipitation of calcium salts.

Procedure for Setting Up Plates

In setting up the plates, 8 ml. of hot agar from a boiling water bath were pipetted into a flat-bottom 90-mm.-diameter petri dish. When this layer of ag had cooled, cylinders 6 mm. inside diameter and 2 long, commercially available in porous porcela cut from glass tubing, were arranged in the de pattern. The pattern used most frequently is sh in Figure 3. A second 8 ml. of very hot agar pipetted around the cylinders. The plate is n tipped or swirled to distribute the agar because sl lines, which interfere with photographic record would be formed in the cooling agar.

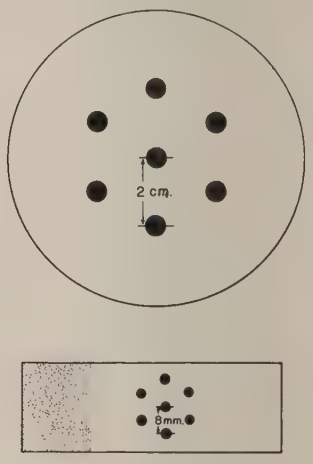

FIGURE 3. Arrangements of wells most often used in agar diffusion methods.

Other authors have recommended the use of m ds of various shapes and sizes to form wells in the ag r. Our experience has been that optimal amounts of i reaction components can best be introduced by usi g the cylinders. The sera or other solutions of solu le antigens were pipetted into the peripheral wells a d the antiserum pipetted into the central well. Wh most systems, 0.25 ml. of each component is adequa e. The plates were sealed with rubber tape, and incuba d at 37°C. for 5 to 7 days. Preliminary observati n were then made and the plates further incubated at 5°C. for 5 to 7 days.

Observations and photographic records were ma e utilizing dark field illumination provided by illuminator designed in this laboratory (Klontz, Ri way, and Wilson, 1960).

Micro Method

We independently developed a micro method f agar diffusion similar to that described by Gras , Pongratz, and Brechbuhler (1956), which has t advantages of requiring only about 0.02 ml. of ea

gent and 12 to 24 hours of incubation. The method is not always suitable for studying very complex systems, however, since the small size of the reaction area does not allow sufficient separation of components. We have found it very useful for preliminary testing of antisera, and use it routinely with those of our antisera in which the reactions are potent and relatively uncomplicated. The micro slides were prepared by pipetting 2 ml. of hot agar base, previously described, onto the 25×55 mm., unfrosted section of scrupulously clean microscope slide. After cooling, wells were punched in the thin layer of agar. The punches used are fabricated from stainless steel tubing of various sizes, and sharpened with an internal bevel. (Machinists call such a tool a dinking die.) The arrangement of the wells most frequently used is shown in figure 3. Capillary pipettes were used to fill the wells with materials to be tested and the slides were incubated in moist chambers 12 to 24 hours at 37°C.

PRODUCTION OF ANTISERA

Most of our antisera have been produced by giving rabbits 7 to 9 intraperitoneal injections of 0.5 ml. undiluted salmon serum in a period of 3 weeks and bleeding them 4 and 7 days after the last injection. From 30 to 60 ml. of blood are taken by heart puncture at each bleeding. After a rest period of approximately 1 month, the rabbit is restimulated by three additional intraperitoneal injections in 1 week and bled on the fourth, fifth, and seventh day after the last injection. Such restimulations and bleedings may be repeated several times. Not all such bleedings from the same rabbit, nor the antisera from different rabbits, are equally useful in detecting the relatively small, racially correlated, antigenic differences in serum components that occur in salmon of a single species. To produce a single, really useful antiserum, it has often been necessary to obtain several bleedings from as many as eight rabbits.

Goats have also been immunized. Incorporation of the antigenic material in Freund's adjuvant has been necessary to obtain a satisfactory initial sensitization for the production of potent precipitating antibodies. Restimulations have been carried out satisfactorily as outlined for rabbits. None of the antisera produced in goats so far has detected racially correlated differences between individual salmon.

Antisera have also been produced in chickens. Chickens have produced antisera which are extremely potent as measured by the usual tube test, in which titrations are conducted by serial dilution of the antigen preparation. Most of these antisera, however, have not been suitable for use in the agar diffusion technique, since most of the precipitation occurs very close to, or in, the antiserum well.

BLOOD SAMPLES

Most of the blood samples taken for this study were obtained by cutting the caudal peduncle or gill of a salmon and collecting the blood in clean screw-cap glass bottles. A few of the samples were taken by cardiac puncture. Samples from Asia and the high seas were whole blood, frozen shortly after collection and kept frozen until used. Samples from American shore areas were placed on cracked ice and shipped by air to the laboratory in insulated containers. In the laboratory, serum was removed from the chilled whole blood samples, freed of cells by centrifugation, and frozen. In a few cases the whole samples were frozen as a check on the method used for Asian and high-seas samples. Some of the samples were also frozen whole after the addition of an equal volume of 40-percent glycerol — 5-percent sodium citrate solution in an attempt to preserve the cells intact. No interference by the glycerol was noted on testing such samples by agar diffusion. All samples were kept frozen at −18° to −30°C. when not in use. No other preservatives were added to any of the samples during storage. Because of the physiological deterioration of spawning salmon, it was found necessary to obtain the blood samples from salmon at least a week before they spawned. Serum from spawned-out salmon frequently lacked important antigenic characters.

RESULTS

INTRASPECIFIC ANTIGENIC DIFFERENCES IN SERUM SAMPLES

The results presented in this paper will be confined to those obtained for red salmon (*Oncorhynchus nerka* Walbaum). Other species of Pacific salmon have been studied to some extent and although encouraging results have been obtained, the studies have not progressed sufficiently to be published.

Small numbers (8 to 12) of blood samples of red salmon were obtained from the Okhotsk Sea in Asia and from several American areas as early as 1955 when these investigations were started. After a number of preliminary experiments, necessary to develop potent antisera and facility with the agar-diffusion technique, we found that one of the antisera, produced in a rabbit by the injection of serum from a Cultus Lake red salmon, would produce 14 lines in the agar-diffusion technique when tested against serum or whole, frozen blood of red salmon. Two of

these lines (antigens) were missing from all eight of the 1955 samples from the Okhotsk Sea but present in 10 of 11 samples taken at Brooks Lake on the Naknek system in 1955. These results were confirmed and extended in tests on samples taken in subsequent years. The two antigenic characters, both of which were missing from most blood samples from Asian areas and either or both of which were present in most blood samples from American areas, were designated antigens I and II. A test for these characters is illustrated in Figure 4.

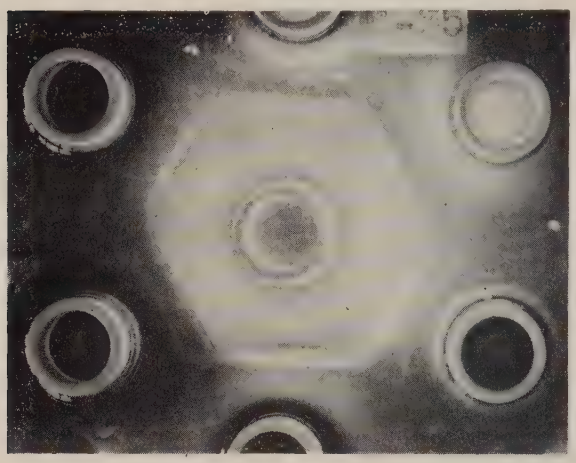

FIGURE 4. Ouchterlony plate demonstrating antigenic differences in red salmon serum samples. The outermost lines, present in positions 1, 2, 3, and 5, and missing from positions 4 and 6 (starting at the top and counting clockwise), are due to components designated antigens I and II.

In our standard testing procedure for antigens I and II, the reaction of each sample was compared with those of a known positive sample and a known negative on the same plate. Independent readings were made by two trained persons. The agreement between readings was excellent, with most antisera used. For example, 294 tests were run on one antiserum with only 8 differences (2.7 percent) between the independent readings of two individual readers. Another antiserum was used to make 462 tests with only 18 differences (3.9 percent) between the independent readings. Samples scored differently by two individual readers were observed further and retested until complete agreement was obtained. If an antiserum did not give sufficiently clear-cut reactions for good agreement between individual readers, the tests were repeated with another antiserum. For example, 390 tests were made with one antiserum with 39 differences (10 percent) in the two independent readings. As a consequence, the tests were repeated with an antiserum, which gave consistent results.

We found the presence of antigens I and II independent of sex. Some evidence is available indicates these antigenic characters are indepe of sexual maturation, diet, and environment. characters were present in 14 of 15 immature 3- old red salmon (*O. nerka*) from the Columbia R reared in captivity and fed standard hatchery pr tion diets. This frequency is consistent with found in maturing red salmon migrating up Columbia River.

TABLE 1. Incidence of antigens I and II in blood samp of red salmon taken in American areas, 1955–58.

Year and area	Number lacking antigens I and II	Num wi anti I or
1955 and 1956:		
Bristol Bay and Kuskokwim	4	8
Karluk	1	2
Cook Inlet	0	1
Ketchikan	0	
Rivers Inlet	1	
Skeena River	0	
Fraser River (Cultus Lake)	1	
Columbia River	3	1
Subtotal	10	17
1957:		
Kuskokwim	0	2
Bristol Bay	2	8
King Cove	0	1
Karluk and Red River	0	5
Cook Inlet	3	1
Prince William Sound	1	1
Southeastern Alaska	0	4
Skeena River	0	4
Fraser River	0	17
Quinault River	2	8
Columbia River	4	56
Subtotal	12	328
1958:		
Salmon Lake (Nome)	2	23
Bristol Bay	0	192
King Cove	0	25
Karluk	4	68
Cook Inlet	0	25
Prince William Sound	2	12
Southeastern Alaska	1	70
Fraser River	0	9
Subtotal	9	424
Total	31	924
Percent	3.2	96

Antigens I and II are lost from the serum of salmon sometime between 1 week before spawning and death, which is not surprising considering the marked physiological degeneration Pacific salmon undergo at this time. These antigenic characters are stable in frozen blood samples held up to 18 months at temperatures from −12° to −35°C. Samples held for longer periods show increasingly weaker reactions when tested for antigens I and II.

INCIDENCE OF ANTIGENS I AND II IN BLOOD SAMPLES FROM AMERICAN AND ASIAN AREAS

The results of tests for antigens I and II on samples obtained from American and Asian areas from 1955 through 1958 are presented in Tables 1 and 2. The American samples are divided into two groups: one from areas north of the Fraser River, the other from the Fraser River and areas south. Within these groups the frequency of individuals possessing antigens I or II or both did not differ significantly between years.

TABLE 2. Incidence of antigens I and II in blood samples of red salmon taken in Asian areas, 1955–58.

Year and area	Date	Number lacking antigens I and II	Number with antigens I or II
55:			
Okhotsk Sea:			
53°32′ N., 155°03′ E	July 22	8	0
56:			
Okhotsk Sea:			
51°09′ N., 154°17′ E	July 15	3	0
51°24′ N., 153°53′ E	16	5	0
51°09′ N., 153°19′ E	16	7	0
51°19′ N., 152°40′ E	23	8	0
Subtotal		23	0
57:			
Northwest Pacific:			
49°58′ N., 159°59′ E	July 5	10	0
50°52′ N., 158°21′ E	13	11	2
Subtotal		21	2
58:			
Okhotsk Sea:			
51°09′ N., 153°40′ E	June 25	9	2
50°55′ N., 153°15′ E	July 17	14	2
East Kamchatka:			
58°52.5′ N., 167°15′ E	June 19	12	2
58°56′ N., 166°57′ E	20	9	2
59°18′ N., 170°38′ E	July 31	20	0
Subtotal		64	8
Total		116	10
Percent		92.1	7.9

The northern group consisted of 835 individuals, 814 or 97.5 percent of which possessed antigens I or II or both. The southern group consisted of 120 individuals, 110 or 91.7 percent of which possessed antigens I or II or both. This difference, although small, is significant (chi square 11.30, with 1 degree of freedom).

The differences in frequency of occurrence of anti-

TABLE 3. Incidence of antigens I and II in blood samples of red salmon taken on United States research vessels, June and July 1957.

Vessel and set	Date	Location		Number with antigens I or II	Number in sample
		Latitude	Longitude		
GROUP A:					
Pioneer:					
1	June 10	50° N.	175° E.	12	20
2	11	50° N.	175° E.	6	18
3	12	50° N.	175° E.	11	17
4	14	53° N.	175° E.	12	22
5	20	53° N.	175° E.	7	10
6	22	53° N.	180°	4	9
Attu:					
4	June 8	53° N.	175° W.	19	36
7	15	56° N.	175° W.	20	31
Pioneer:					
7	June 29	56° N.	175° W.	1	5
8	30	56° N.	175° W.	4	11
9	July 3	53° N.	175° W.	1	1
10	4	53° N.	175° W.	1	4
11	6	50° N.	175° W.	0	1
13	8	51° N.	176° W.	11	18
Total				110	202
Percent				54.5	
GROUP B:					
Pioneer:					
14	July 16	56° N.	175° E.	2	4
15	19	53° N.	175° E.	3	3
17	22	50° N.	175° E.	3	3
18	23	52° N.	175° E.	2	2
19	24	53° N.	175° E.	1	1
20	25	54° N.	175° E.	1	1
21	26	55° N.	175° E.	1	1
22	27	56° N.	175° E.	1	1
23	27	56° N.	175° E.	1	1
24	28	56° N.	175° E.	3	3
Paragon:					
2	July 22	50° N.	175° W.	2	5
6	27	56° N.	175° W.	1	1
7	28	56° N.	175° W.	1	1
8	30	53° N.	175° W.	1	1
Total				23	28
Percent				82	

TABLE 4. Incidence of antigens I and II in blood samples of red salmon taken by United States research vessels, August 1957.

Vessel and set	Date	Location		Number with antigens I or II	Number in sample
		Latitude	Longitude		
GROUP C:					
Pioneer:					
28	Aug. 11	53° N.	175° E.	2	5
29	12	53° N.	175° E.	3	7
30	13	54°13′ N.	175° E.	0	2
31	14	56° N.	175° E.	4	5
32	17	53° N.	175° E.	6	9
33	18	53° N.	175° E.	4	8
36	23	51°30′ N.	175° E.	5	9
37	24	53° N.	175° E.	5	6
Paragon:					
11	Aug. 6	51°30′ N.	175° W.	7	12
12	7	51° N.	175° W.	14	26
13	8	50° N.	175° W.	10	27
14	9	50° N.	175° W.	14	38
15	12	53° N.	175° W.	2	2
19	17	53° N.	175° W.	0	1
20	18	53° N.	175° W.	1	1
21	20	50° N.	175° W.	6	17
22	21	50° N.	175° W.	12	20
23	22	51° N.	175° W.	7	21
24	23	51°30′ N.	175° W.	4	6
Total				106	222
Percent				47.7	

gens I or II or both among the various Asian samples are not significant. Among 126 Asian red salmon samples only 10 or 7.9 percent possessed these characters. Since we have not yet been able to develop an antiserum that will readily distinguish between these two antigens in every case, we report the presence of either or both of them as positive and their complete absence as negative.

INCIDENCE OF ANTIGENS I AND II IN BLOOD SAMPLES FROM HIGH-SEAS AREAS

In 1956, nine red salmon blood samples were collected in the eastern Bering Sea (54°–60° N., 160°–170° W.) by the biologist on the chartered vessel MV *Tordenskjold*. Eight of these samples were positive for antigens I or II or both and thus similar to our American standards from shore stations in that area.

In 1957, many blood samples were taken by the American biologists on the motor vessels chartered for research in the North Pacific and Bering Sea. All samples taken on the MV *Attu* after June 15 were found to be unsuitable because of failure of the refrigeration system; consequently, high-seas samples were avail ble only from the area bounded by 175° W., 175° 50° N., and 55° N. These samples are divided in three groups, A, B, and C, according to time of c lection. These groups are also characterized by t proportion of mature red salmon in the catch and t number of red salmon caught. The results are p sented in Tables 3 and 4.

Most red salmon sampled in groups A and B we mature, but the majority of the fish sampled in gro C were immature (from evidence of age and gonac development). The catches of red salmon were go in groups A and C but poor in group B.[1]

Within each of these groups the proportion of in viduals possessing antigens I or II or both does n differ significantly among sets or with longitud The proportion of individuals possessing these chara ters does differ significantly between groups (c square 13.9, with 2 degrees of freedom), indicati considerable variability with time.

Since the proportion of individuals possessing an gens I or II or both did not differ significantly with each group, the samples were combined to obta estimates of the proportion of red salmon possessi these characters within the space and time boundar sampled. In group A, consisting of samples tak between June 8 and July 8, were 202 individuals, which 110 or 54.5 percent possessed antigens I or or both. In group B, consisting of samples taken fro July 16 to July 30, were 28 individuals, of which or 82 percent possessed these antigenic characters. group C, consisting of samples taken from August to August 23, were 222 individuals, of which 106 47.7 percent possessed antigens I or II or both.

Because of the high incidence of antigens I and in red salmon samples of American origin and a c respondingly low incidence in samples of Asian orig estimates of the incidence of these two antigens populations sampled on the high seas are also estima of the proportion of red salmon of American ori present in the area during the periods of sampli These estimates could be corrected for the amount overlap; however, the correction does not grea change the value of the estimates and seems rat extravagant considering the number of individ samples available from the various sets. It wo thus appear from the data in Tables 3 and 4 that th was considerable intermingling of American a Asian stocks of red salmon in the high-seas ar

[1] Catch data are available in the Annual Report for 195 the International North Pacific Fisheries Commission (1958

TABLE 5. Incidence of antigens I and II, in blood samples of red salmon taken by United States and Japanese research vessels, late May, June and July, 1958.

Vessel and set	Date	Location		Number with antigens I or II	Number in sample
neer:					
2	May 28	53°00′ N.	178°15′ E.	2	6
3	30	55° N.	174°00′ E.	3	5
4	31	54° N.	173°00′ E.	6	12
5	June 1	53° N.	172°00′ E.	2	4
u: 5	June 7	53°07′ N.	175°02′ E.	0	1
neer: 6	8	51°35′ N.	173° E.	5	6
u:					
6	June 9	54° N.	178° W.	0	1
7	16	53°30′ N.	170°02′ W.	1	8
neer: 8	June 18	54° N.	180°	1	3
kashio aru:					
No data	June 18	56° N.	172°30′ W.	11	16
No data	19	56° N.	172°50′ W.	4	6
u:					
10	June 24	55°04′ N.	169°24′ W.	7	16
11	25	55°58′ N.	170°04′ W.	2	4
neer:					
11	July 6	51°17′ N.	175°53′ W.	7	13
12	7	50°30′ N.	175° W.	1	2
13	8	49°30′ N.	175° W.	1	1
u: 18	July 11	52°04′ N.	178°38′ W.	3	4
neer:					
15	July 12	50°59′ N.	178°50′ W.	7	7
16	13	50°18′ N.	177°28′ E.	4	5
u:					
20	July 13	53°31′ N.	180°	0	3
21	14	54° N.	178° E.	2	3
neer:					
17	July 14	49°39′ N.	176°11′ E.	1	1
18	15	49° N.	175° E.	5	7
19	16	50° N.	175° E.	1	4
20	17	51° N.	175° E.	2	3
21	18	52° N.	175° E.	2	3
24	21	52°07′ N.	176°55′ E.	1	1
u:					
23	July 16	54° N.	175° E.	1	1
24	17	55° N.	175° E.	0	2
27	20	54° N.	174°58′ E.	0	2
neer: 29	July 27	52°58′ N.	175°13′ W.	0	2
Total				82	152
Percent				53.9	

TABLE 6. Incidence of antigens I and II in blood samples of red salmon taken by United States and Japanese research vessels, August 1958.

Vessel and set	Date	Location		Numder with antigens I or II	Number in sample
Pioneer:					
31	Aug. 5	51°30′ N.	175° W.	8	16
32	6	50° N.	175° W.	13	23
33	7	49° N.	175° W.	4	10
34	9	49° N.	170° W.	3	4
35	10	50° N.	170° W.	3	9
36	11	51° N.	170° W.	1	2
Attu:					
33	Aug. 16	52° N.	165° W.	7	11
34	17	51° N.	165° W.	2	8
35	18	50° N.	165° W.	7	10
Total				48	93
Percent				52	
Wakashio Maru	Aug. 7	55° N.	164° E.	6	25
Percent				24	

pled in 1957.

The precision of the estimates presented is dependent several factors. Among these factors are the resentativeness of the samples obtained for the ual populations of red salmon present in the area ring the sampling periods and the representativeness of the Asian and American reference samples for the actual populations involved in the high-seas areas. Since it may not be practical or even possible to evaluate these factors directly, the research program of the International North Pacific Fisheries Commission is designed to allow the testing of such estimates by several independent methods. These methods include tagging and the study of morphological and scale characteristics. We expect that in the future additional, as yet undiscovered, serological characters will also be available for use.

Because of bad weather and lower availability of red salmon, fewer blood samples were taken by American research vessels in 1958 than in 1957. The results of tests for antigens I and II on the 1958 blood samples taken in the North Pacific and Bering Sea areas by United States and Japanese research vessels are presented in Tables 5 and 6. Of 152 samples taken in late May, June, and July, 82 or 53.9 percent possessed antigens I or II or both (Table 5). Of 93 samples taken from immature red salmon in August south of the Aleutian Islands from 175° W. to 165° W. and from 49° N. to 52° N., 48 or 52 percent possessed antigens I or II or both (Table 6).

The proportion of individuals possessing these antigenic characters does not differ significantly among sets nor among groups when the samples are grouped in several ways according to time or longitude. This lack of difference may be due to the small numbers

of individuals sampled in each set and thus be more apparent than real.

Blood samples were taken from a group of 22 red salmon on the Japanese research vessel *Wakashio Maru* in the Bering Sea. Sixteen of the fish were obtained on June 18, at 56° N., 172°30′ W., and an additional six were obtained on June 19 at 56° N., 172°50′ W. Of these 22 samples, 15 or 68 percent were positive for antigens I and II. Although the difference is not significant, the incidence is somewhat higher than the average in the samples taken by American vessels (Table 3) and is indicative of a possible concentration of salmon of American origin in the area sampled.

Most of the red salmon from which the 25 blood samples were taken on the Japanese research vessel *Wakashio Maru* at 55°N., 164°E. on August 7, 1958, were immature. Because of the lateness of the season and the immaturity of the fish, this sample cannot be considered an Asian standard. Of these 25 fish, 6 or 24 percent were positive for antigens I or II or both, a significantly higher incidence than in the other Asian samples (chi square 4.14, corrected for continuity 1 d.f.). Among the possible explanations for the higher incidence are the following:

First, the sample may be one of 5 out of 100 which would not fall within the 95 percent confidence intervals. Secondly, the fish may represent some, as yet unsampled, Asian area which has a higher incidence of antigens I or II or both than those sampled. A third possibility, which is of considerable importance in the Protocol problem of the International North Pacific Fisheries Commission, is that immature red salmon from American areas may migrate in measurable numbers as far west as 165°E. late in the season. Data presently available do not exclude this possibility.

SEX-AND-MATURITY-CORRELATED ANTIGEN IN SERA OF FEMALES

In addition to the area-correlated differences in the serum components of red salmon, an antigenic component probably unique to mature or maturing females was found in their sera (Fig. 5). This character was present in the serum of only 6 males of 504 checked. These exceptions were probably due to errors in labeling the samples. Most samples possessing this character were females with gonads greater than 10 grams in weight. This antigenic character was also present in high concentration in the eggs of salmon. Similar components have been demonstrated in the sera of laying hens (Sasaki, 1932) and mature female carp (Uhlenhuth and Kodama, 1914). The characters involved have been extensively studied in chicks and found to be phosphoproteins of the vitellin fraction, synthesized in the liver under hormonal control (Vanstone, Maw, and Common, 1955).

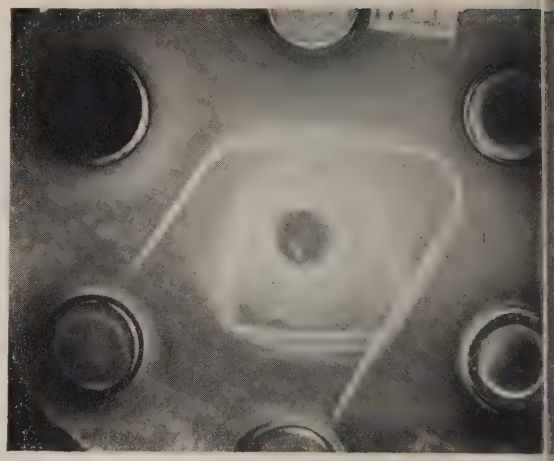

FIGURE 5. Ouchterlony plate demonstrating antigenic differences in red salmon serum samples. The line present in positions 1, 2, 3, and 6 and missing from positions 4 and 5 (starting at top and counting clockwise) is due to antigenic components found in the sera of mature or maturing female salmon and in their eggs.

In salmon, this antigenic character was detectable in samples taken in early June from 4-year-old Columbia River red salmon reared in captivity that would not spawn until October. Only a small drop of blood is required for determining its presence. Its applicability in determining whether fish caught on the high seas are maturing is under investigation.

DISCUSSION

The results of the research reported in this paper demonstrate the utility of specialized serological and immunochemical methods in some of the most important problems of fishery biology, racial identification, and sexual maturation. The methods described are also being applied to species identification problems and work is progressing on the use of other specialized serological methods in racial or subpopulation identification problems. Especially important are the blood-grouping methods discussed in two previous papers (Ridgway, Cushing, and Durall, 1958; Ridgway and Klontz, 1960) from this laboratory and in the work of Hildemann (1956), Cushing and Durall (1957), and Sindermann and Mairs (1959). The accumulation of basic knowledge about blood groups and other serological characteristics of fish is, unfortunately a

process, as only a relatively small number of tigators are studying the commercially important ps of fish from this standpoint.

he methods presently available require fresh or -frozen samples. When methods of preservation convenient for field use are developed, blood ping and other immunochemical methods should increasingly practical application in modern ry biology.

he preparation of sufficient antisera with the neces- specificity was one of the most important lems in the present study. Several methods of aring antisera with increased potency and specifi- are presently being studied. An important con- ration in producing antisera to detect racial rences in the serum antigens of fishes is to use the sera of males for injection. If sera of mature les are used for injection, antibodies are produced nst the antigenic components present only in the m of mature females. Reactions with these ponents complicate the tests and may confuse or k racially correlated differences.

he best antisera produced in the present study he detection of differences between American and n red salmon were obtained by injecting sera of salmon from areas in the southern part of this ies' range in America (Cultus Lake and Adams r). These antisera would react with antigen I II components of northern American samples but with any corresponding components in Asian ples. When antisera were prepared with serum n red salmon of Bristol Bay origin, considerable s-reactivity with corresponding components in the n samples was obtained. Probably a complex s of overlapping specificities is involved, analogous hat found in the A-B-H-*Lewis* soluble blood-group stance of humans (Brown, Glynn, and Holborow, 9).

f methods can be perfected for the production of iciently potent and specific antisera, studies into chemical nature of the compounds involved and mechanism of their inheritance are possible.

Concerning the nature or cause of the difference ween individual red salmon samples possessing tigens I or II and those lacking them, the most ly possibility, and one leading to useful information cerning the continental origin of samples taken on high seas, is that the differences are due to differ- es in the genetic constitution of the individual red non. The much higher incidence of the characters lood samples from red salmon of American origin than in those from red salmon of Asian origin would reflect a much higher frequency of the determining gene or genes in the American populations. Such differences in gene frequencies between reproductively isolated populations have been demonstrated in many animal species (Dobzhansky, 1951) and would be expected to result from the reproductive isolation of salmon populations imposed by the precision of their home-stream migrations (Scheer, 1939), their adaptation to their area of origin (Davidson and Hutchinson, 1938), and the precise chronology of the spawning migrations of each race (Killick, 1955).

The possibility that antigens I and II are two relatively unstable antigens lost from some of the samples because of selective deterioration, brought about by some difference in the sampling methods or conditions, seems unlikely because individual samples taken in the same area and under conditions as nearly identical as possible differ in their antigen-I and -II reactions. Also, improper preservation of samples is usually detectable in the agar-diffusion test because of a general diffuse reaction, with lines due to antigens other than I and II missing or weak.

The problem of representativeness of samples has been discussed briefly under Results. Studies of this nature are, of course, dependent on adequate and representative sampling; and adequate, representative sampling of the races of salmon in the North Pacific and Bering Sea is difficult.

It should also be pointed out that a substantial proportion of the red salmon samples taken east of 180° in the Bering Sea were scored negative for antigens I and II. This is inconsistent with the general belief that nearly all such fish are of American origin and probably indicates that some complicating factors are resulting in false negative tests for these antigens. The nature of these factors is under investigation.

For these reasons, estimates made in this paper should be considered preliminary and are only estimates of average values for rather extensive areas and time intervals.

SUMMARY

The sera of most Alaskan red salmon contained at least 14 antigenic components when tested with rabbit antisera by the double diffusion precipitin analysis method of Ouchterlony.

Two antigenic serum components, designated antigens I and II were missing from 116 of the 126 blood samples of red salmon collected in Asian areas in

1955, 1956, 1957, and 1958. Of 955 blood samples collected in American areas in the same period, only 31 lacked these components.

Variable frequencies of antigens I and II occurred in blood samples collected from red salmon taken in the Central North Pacific and Bering Sea. Some significant differences in these frequencies were found among the areas sampled and times of sampling. However, the number of individual samples taken in any given area and at any given time usually were too small to provide very precise estimates of the frequency of occurrence of these antigenic characters in the population sampled. In 1957, the average frequency of these two characters in the area bounded by 50°N., 55°N., 175°E., and 175°W. was 54.5 percent from June 10 to July 8, 82 percent from July 16 to July 30, and 47.7 percent from August 6 to August 24. In 1958, the number of individual blood samples of red salmon taken at each set was small and no significant differences in the frequency of occurrence of antigens I and II were detected. The average frequency was 53.9 percent in 152 samples taken between May 28 and July 27 in the area bounded by 49°N., 55°55′N., 172°E., and 169°24′W. A 68-percent frequency was found in one group of 22 blood samples of red salmon taken by a Japanese research vessel at 56°N., 172°30′W. and 56°N., 172°50′W. on June 18 and 19. Of 93 samples taken from immature red salmon between August 5 and 18 from 175°W. to 165°W. and 49°N. to 52°N., 48 or 52 percent possessed antigens I or II or both.

Results of this study are considered indicative of intermingling of Asian and American stocks of red salmon over broad areas of the North Pacific and Bering Sea.

An antigen (or antigens) was discovered that occurs in the sera of only mature or maturing female red salmon.

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APPENDIX H

REQUIRED INSTRUMENTS FOR FISHERIES RESEARCH

by

Dr. Julius Rockwell, Jr., and Fisheries Instrumentation Committee of the Bureau of Commercial Fisheries

PREFACE

The Bureau of Commercial Fisheries requires other instruments to meet its special needs in addition to those described in preceding appendices. The nature and purpose of descriptions, priorities, readouts for the National Oceanographic Data Center, modular construction, and additional general requirements as well as estimates of numbers required, have been covered in the preface of appendix E (p. 349).

The sensor modules (Section 1.1100) represent the most vital and the least developed part of all systems. Existing telemetering devices may be adequate except for special applications.

Two basic areas of instrumentation are covered: instruments or instrument systems for measuring and recording physical and chemical parameters, and those for sampling, collecting, or studying the biota. The list is not complete because in some areas the basic instrumentation problem of calibrating devices designed to collect quantitative biological samples has not been solved.

The stated requirements of instruments to collect biological samples imply, in general, improvements and refinements of existing techniques rather than the development of entirely new approaches. For example, in Sections 1.3200 and 1.3300, sampling devices which consist of plankton or nekton nets, instrumentation is intended to accommodate existing nets. While it is desirable to construct new collecting devices, the basic information of how animals react to them is lacking. The purpose of these devices is, in general, to obtain a quantitative estimate of living creatures and plants per unit volume of the water body. Research in this area is urgently needed before better collecting devices can even be suggested. Also, there is an equal need for an understanding of

the hydrodynamics of existing sampling devices.

More than one modular form has been described for sensing a given characteristic of the water. The basis of separation has been use. It would be desirable if several of these could be combined at no extra cost. If a decided cost advantage would result by dividing the range of capability of a module still further, the Bureau should be consulted.

It may be desirable from the manufacturer's standpoint to combine several sensors into one module -- such as the dissolved gas sensors (Section 1.1160). It will not be mandatory to use separate modules for each sensor providing it can be demonstrated to be to the Bureau's advantage to combine them.

The effect of one environmental factor on the sensor of another can be significant. The effect of depth is the most pronounced since it may subtly affect the operation of the electronic components, as well as the sensing element. (See pages 32-35.) In general, sensors should be self-compensating.

It is suggested that a manufacturer having a capability for making a product very similar to one that appears on the list contact the Bureau to determine a group with which he can work, and the extent and nature of support he can expect without impairing his right to patent.

The Bureau buys what is available and makes what is not available and will work with Industry to build a more serviceable instrument.

The following general requirements are applicable to most of these instruments and instrument systems. They must:

1. Operate in severe environments, particularly ones of high humidity and salt corrosion and withstand storage temperatures of from -25° to 60° C.;

2. Resist vibration and shock;

3. Have high reliability and long life;

4. Provide for accurate calibration on board ship;

5. Be simple to operate and be easy to maintain;

6. Be compact and portable; and,

7. Meet requirements of NODC.

The general number of items required by the Bureau is indicated subject to the availability of funds and tolerable costs. These figures do not include those that may be required by state and international agencies or by commercial fishing enterprises.

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1.0000 FIELD EQUIPMENT

Numbers required

1.1000 SYSTEM COMPONENTS (See p. 415.)

1.1100 SENSOR MODULES

1.1110 Temperature (3 modules).

Range and accuracy:

(1) -2° to 45° C. ±0.1° C. at depths 0 to 500 m. . . . . (47)

(2) -2° to 35° C. ±0.01° C. at depths 0 to 500 m. . . . . (554)

(3) -2° to 35° C. ±0.01° C. at depths 0 to 12,000 m. . . . . (121)

Response: 95% in 0.5 second.

1.1120 Salinity (3 modules).

Range and accuracy:

(1) 0 to 45‰ ±0.2‰ at depths 0 to 500 m. . . . .(46)

(2) 25 to 40‰ ±0.01‰ at depths 0 to 500 m. . (537)

(3) 25 to 40‰ ±0.01‰ at depths 0 to 12,000 m.(120)

Response: 95% in 0.5 second including flushing time.

Temperature compensation: -2° to 45° C.

1.1130 Pressure (depth) (4 modules).

Range and accuracy:

(1) 0 to 50m. ±0.25%. . . . . (25)

(2) 0 to 500 m. ±0.5%. . . . . (542)

(3) 0 to 2,500 m. ±0.5%. . . . . (125)

(4) 0 to 12,000 m. ±0.5%. . . . . (56)

Response: 95% in 1 second.

Temperature compensation: -2° to 35° C.

1.1140 Density (2 modules) (In situ directly as opposed to computation from temperature, salinity, and pressure).

Range and accuracy:

(1) 0.9800 to 1.0320 g./cm.^{3} ±0.0001 at depths 0 to 500 m. . . . . (48)

(2) 1.0200 to 1.0400 g./cm.^{3} ±0.00002 at depths 0 to 2,500 m. . . . . (112)

Operating environment: -2° to 35° C.

1.1150 pH (2 modules).

Range and accuracy:

(1) 0 to 8 pH units ±0.03 at depths 0 to 500 m. . (29)
(2) 6 to 14 pH units ±0.03 at depths 0 to 500 m. . . . . (56)

Response: 95% in 1 second including flushing time.
Operating environment: -2° to 45° C.; Salinity 0 to 45‰.

1.1160 Dissolved Gases[1/]

1.1161 Oxygen (3 modules).

Range and accuracy:
(1) 0 to 15 ml./l. ±0.02 at depths 0 to 50 m. . (47)
(2) 0 to 10 ml./l. ±0.02 at depths 0 to 500 m. . (535)
(3) 0 to 10 ml./l. ±0.02 at depths 0 to 2,500 m. . . . . (118)

Response: 95% in 1 second including flushing time.
Operating environment: -2° to 45° C.; Salinity 0 to 45‰.

1.1162 Carbon Dioxide. . . . . (44)

Range and accuracy:
0 to 4 ml./l. ±0.01 at depths 0 to 500 m.
Response: 95% in 1 second including flushing time.
Operating environment: -2° to 45° C.; Salinity 0 to 45‰.

1.1163 Hydrogen Sulfide. . . . . (19)

Range and accuracy:
0 to 5 ml./l. ±0.5 at depths 0 to 500 m.
Response: 95% in 1 second including flushing time.
Operating environment: -2° to 45° C.; Salinity 0 to 45‰.

1.1164 Nitrogen. . . . . (17)

Range and accuracy:
0 to 5 ml./l. ±0.02 at depths 0 to 500 m.
Response: 95% in 1 second including flushing time.
Operating environment: -2° to 45° C.; Salinity 0 to 45‰.

1.1170 Light.

1/ Two or more may be combined in one module if economically desirable.

1.1171 Incident visible irradiance (to monitor ambient visible irradiance at surface during submarine irradiance measurements). . . . . .(62)

Range and accuracy:

0 to 1 g. cal./cm.^{2}/min. ±0.1% (for visible light only)

Specifications and requirements:

(1) Remote controlled filter-changing mechanism.
(2) Equipped with a cosine collector.
(3) Gimbal-mounted.

Operating environment: Exposed marine atmosphere, tropical to polar.

1.1172 Ambient irradiance (to measure visible irradiance in situ at depth). . . . . .(73)

Range and accuracy:

0.001 to 1.1 g. cal./cm.^{2}/min. ±2% at depths 0 to 500 m.

Specifications and requirements:

(1) Detectors shall be provided with cosine collectors and be capable of being oriented in any direction.
(2) Provision in some designs to measure the spectral distribution of light.

Operating environment: -2° to 45° C.

1.1173 Beam Transmission (to measure the absorption and scattering of light in water). . . . . (207)

Range and accuracy:

0 to 100%/m. ±0.05% at all wave lengths.

Specifications and requirements:

(1) Capable of employing a variety of interference-type filters which may be changed while submerged.
(2) Capable of operation in full sunlight.
(3) Design to provide adequate flushing when in motion.
(4) Can be towed up to 15 knots.
(5) Path lengths adjustable (a) 5 to 50 cm. (b) 50 to 200 cm.

1.1180 Current (2 modules).

Range and accuracy:

(1) 0 to 4.0 m./sec. ±0.1 at depths of 0 to 500 m. . . . . .(131)
(2) 0 to 1.0 m./sec. ±0.03 at depths 0 to 2,500 m. . . . . (38)

Direction: Accurate to ±5°.
Operating environment: -2° to 45° C.

1.1200 COMMUNICATION MODULES.

1.1210 Data Telemetering Module. . . . . (96)

Purpose: To accept the output from up to six standard data sensors and transmit this information to the surface monitoring and recording unit.

Specifications and requirements:

(1) Operating environment:
  (a) Temperature: -2° to 50° C.
  (b) Depth: Maximum of 12,000 m.
  (c) Cable length: Maximum of 18,000 m.
(2) The total underwater system including the sensors shall not require more than one 3-conductor cable excluding the strength member. This cable shall supply the required power.
(3) The total system may have up to 20 telemetering modules on one cable.

1.1220 Cables (A family of improved steel cables which contain electrical conductors). . . . . .(76,000 m.)

Purpose: To serve as towing, trawling, and support cables for research survey and commercial fishing gear and to serve as electrical conductors for instruments and equipment.

Specifications and requirements:

(1) Must be compatible with anticipated uses in telemetry, television, control, lighting, fish shocking, and power supply.
(2) Must be able to withstand severe conditions of pressure, temperature, tension, torsion, shock, chafing, abrasion, vibration, and repeated bending over small radius sheaves.
(3) Must have life expectancy greater than presently available cable.

1.1230 Buoy Location Transponder.

Purpose:

(1) For position fixing in making oceanographic measurements.

(2) For locating free floating or anchored buoys, instrument capsules, and nets.

1.1231 Buoy or Instrument Capsule-mounted Transceiver Module. . . . . (135)

Specifications and requirements:

(1) The unit shall transmit a coded identification signal whenever it is activated by a coded interrogation signal.

(2) The unit shall not respond to any signal that does not contain its own particular code.

(3) The transmitter shall turn itself off when transmission is completed. Duration of transmission shall be no longer than required by the interrogator for obtaining its bearing.

(4) It shall be possible to change the code by replacing a plug-in unit within the module.

(5) The range shall be at least 50 miles when used with the shipboard or airborne interrogator.

(6) The module shall contain internal batteries or other power supply sufficient for at least 30 days of continuous receiver and intermittent transmitter operation. Provision shall be available to increase life of power supply to at least 6 months. No maintenance shall be required during this period.

(7) Only nonspillable or dry batteries shall be used.

(8) The module shall be capable of normal operation without maintenance after being submerged to a maximum depth of 2,500 meters for at least 30 days.

(9) The module shall operate reliably over the temperature range of -25° to 50° C.

(10) The maximum weight of the module complete with antenna and internal power source shall not exceed 40 pounds, exclusive of pressure case, if any.

1.1232 Shipboard or Airborne Interrogation Module. . . (25)

Specifications and requirements:

(1) This module shall allow the operator to interro-

gate selectively, identify, and determine the bearing of each buoy or capsule-mounted module.

(2) It shall operate from internal, non-spillable, rechargeable batteries.

(3) It shall operate reliably over a temperature range of -25^{o} to 50^{o} C.

(4) Maximum weight including batteries shall not exceed 30 pounds.

1.2000 VEHICLES.

1.2100 TOWED VEHICLES.

1.2110 Parameter Following Device (three models for 3 depth ranges).

Purpose: To provide a vehicle that will follow constant value of a given parameter, and carry special sensor modules and other equipment.

Specifications and requirements:

This device is to be used on an electrically conducting cable and will be towed from a vessel at speeds up to 15 knots.

(1) Depth:

(a) 0 to 50 m. . . . . .(8)

(b) 0 to 500 m. . . . . (27)

(c) 0 to 2,500 m. . . . . (16)

(2) The device shall contain any or all of the standard or special sensor modules. Continuous surface monitoring of the outputs of these modules is required.

(3) The parameter being followed shall be selectable from the surface. It shall also be possible to vary the level of the parameter being followed within the full range of the respective sensor module, providing the depth capability is not exceeded.

For example, the device shall be capable of following one temperature level and upon command from the surface proceed directly to any other temperature level that the operator selects. It shall then follow this new level. If the operator desires to stop following the temperature level, he may by turning a switch command the device to follow any other parameter for which there is a sensor module. Similarly, the level of the new parameter

being followed shall be continuously variable from the surface.

(4) Accuracy in following any level of any parameter shall be limited only by the accuracy of the standard sensor modules and the response time of the entire system.

(5) Utility of the system is directly dependent upon fast vehicle response time.

(6) The device shall position itself by controllable vanes or fins and/or by a winch aboard ship.

(7) Provision shall be made for the attachment of detection, observation, and sampling devices. The effect of these attachments upon the guidance or positioning system should not impair the unit's ready response to variables.

1.2200 TETHERED VEHICLES.

1.2210 Self-Propelled Robot Vehicle. . . . . .(5)

Purpose: To operate from ships of opportunity to carry sensing elements for vertical profiles while the ship is underway without necessity for special installation of heavy winch and boom on board.

Specifications and requirements:

(1) Must have a streamlined body which can be towed (or powered through cable) astern of ship traveling at speeds 15 to 20 knots for distances up to 4,000 miles. By guidance system and with power supplied through cable, vehicle could be made to dive without heavy strain on cable, or to move forward of ship and sink to depth required as ship passed over. It might also be operated continuously at constant or varying depth below ship throughout trip.

(2) It must be capable of operation from surface to depths of 300 m.

1.2300 FREE VEHICLES.

1.2310 Large Submersible Research Vessel. . . . . .(4)

An oceanographic research vessel capable of independent operation from the surface to at least 300 meters for observing the behavior of organisms in relation to their

environment. For this purpose we envision a boat of approximately 40 meters, with an Albacore-type hull, a sail, a submerged speed of 20 knots, and capable of dives of at least 8 to 10 hours at full speed for a large part of the diving time. The ability to operate more or less continuously underwater would greatly increase the usefulness of such a vessel. It would have viewing ports, water and plankton sampling devices, television, several kinds of acoustical gear, a suit of modular sensors with readouts on board, and remote manipulators. A converted Navy submarine would not be suitable.

1.2320 Small, Manned, Pressure Resistant Vehicle. . . . . (10)
There is also need for a much smaller vehicle for two or three men, which could operate from a mother ship.

1.2330 Drone. . . . . (8)
An instrumented surface or subsurface vessel which could either be programmed to a search pattern or commanded from a mother ship or shore, to operate at depths of up to 500 m.

1.3000 SAMPLING DEVICES.

1.3100 WATER.

1.3110 Micro Water-sampler. . . . . (26)
Purpose: A device for obtaining a small water sample from a thin stratum.
Specifications and requirements:
(1) Capacity: 10 to 50 ml.
(2) Filling time less than 10 sec.
(3) Must sample a stratum of 2 cm. or less without drawing in water from strata above or below that being sampled.
(4) Positioning of this sampler above the bottom to within ±2 cm. is necessary.

1.3200 PLANKTON.

1.3210 Low Speed Plankton Sampler Frame. . . . . (75)
Purpose: To provide opening and closing capability and environment sensor carriage for standard 1-meter, 1/2-meter, and other conventional plankton nets.

Specifications and requirements:

(1) Contain a mechanism which will open and close net on command.
(2) Permit installation of conventional flowmeter.
(3) Permit simultaneous use at intervals along the towing wire.
(4) Opening and closing of nets, when more than one net is used in series, should be simultaneous to within ±1 min. per 100 m. of towing cable length.
(5) The opening and closing events on each net shall be automatically recorded.
(6) The opening-closing commands may be given either from the vessel and/or by preprogramming.
(7) Operate down to 2,500 m. and from 1/2 to 3 knots.

1.3220 High Speed Plankton Sampler Frame. . . . . .(75)

Purpose: To collect at high speed a quantitative plankton and larval sample at a specified depth and to measure the environmental parameters encountered.

Specifications and requirements:

(1) Net to open and close on signal from ship.
(2) Mouth openings of from 2 to 20 cm. diameter to be provided either adjustably or interchangeably before tow.
(3) To accept all or any of the environmental parameter sensors.
(4) To measure volume of water filtered to within ±5%.
(5) So constructed to permit simultaneous use at intervals along towing wire.
(6) To operate down to 500 m. and from 5 to 15 knots.

1.3300 NEKTON

1.3310 High Speed Nekton Net. . . . . (50)

Purpose: To improve present designs of collecting nets which will quantitatively sample nekton.

Specifications and requirements:

(1) Range: 0 to 500 m.
(2) To fish at desired depth controllable to within 3 m.

(3) Operating speeds 5 to 18 knots desired.
(4) Include standard sensing modules.
(5) Include a water meter device.

1.4000 BIOTA OBSERVATION.

1.4100 ECHO RANGING DEVICES.

1.4110 Fish Detector - Shipboard Mounted. . . . . .(37)
Purpose: To detect schools and individual fishes at greater ranges than presently attainable and permit determination of size and species of individual fishes and abundance.
Specifications and requirements:
(1) Manual and automatically trained transducers.
(2) Transducer stabilized for roll of ship.
(3) 360° transducer with PPI scope and chart recorder.
(4) Range: 0 to 100 m., 0 to 1,000 m., 0 to maximum.
(5) Spectrum analyser circuit for target evaluation.

1.4120 Fish Detector - Gear Mounted. . . . . .(26)
Purpose: To determine the catching efficiency of fishing gear, particularly trawls.
Specifications and requirements:
(1) Remote recording via conducting cable.
(2) Automatic 360° scanning normal to axis of trawl.
(3) Range: 0 to 100 m.
(4) Operating depth: 0 to 500 m.

1.4130 Whale Detector - Tethered. . . . . .(1)
Purpose: To count migrating gray whales.

1.4200 WEIGHING DEVICES.

1.4210 Shipboard Weighing Machine (4 modules).
An accurate, rapid weighing machine for use on shipboard to weigh objects of the following groupings:
(1) 0 to 50 g. . . . . .(25)
(2) 0 to 500 g. . . . . (22)
(3) 0 to 5 kg. . . . . (17)
(4) 0 to 50 kg., all within ±1% with printed and punched tape readout. . . . . .(16)

1.4300 SPECIAL TELEVISUAL DEVICES

1.4310 Fisheries Research Underwater Television. . . . . .(1)

Purpose: To provide positive visual information regarding behavior of fishes, environmental conditions, reaction of fish to fishing and sampling gear, performance of fishing and sampling gear unrestricted by seasonal, light, turbidity, or weather conditions.

Specifications and requirements:

(1) Miniaturized camera and monitoring unit.
(2) Depth range:
    (a) 0 to 500 m.
    (b) 0 to 2,500 m.
    (c) 0 to 12,000 m.
(3) Remote focus, iris, and scanning controls.
(4) Electronic visible or infrared lighting system with intensity, interruption, frequency, and on-off duration controls.
(5) Independently battery powered for 24-hour period.
(6) Fitted with device to allow camera to travel along track line attached to moving and stationary fishing gear, sampling gear, or sea bed.
(7) Adaptable to separate electrical or combination electrical-towing cable.

1.5000 SYSTEMS.

1.5100 OCEANIC BUOY SYSTEMS.

1.5110 Buoy System (Continuous or intermittent recording for storage and/or transmission upon interrogation) . . .(119)

Purpose: To provide for the collection, recording, storage, and/or transmission of important meteorological and oceanographic data utilizing moored buoys.

Specifications and requirements:

(1) For anchoring in depths of 10 to 12,000 m.
(2) Designed to operate unattended for 1 to 6 months.
(3) Designed to transmit data to a shore station upon interrogation 0 to 3,000 (nautical) miles away or upon interrogation by ships or airplanes 0 to 100 (nautical) miles away.
(4) Subsurface sensors located at a maximum of 20 different levels down to 500 m.
(5) 3 to 6 different standard sensor modules at each level.
(6) Sensors on or above the buoys to measure sea

surface temperature, air temperature, barometric pressure, wind speed, wind direction, humidity, incident radiation, and reflected radiation. (Sensors for the latter two parameters must provide data which meet specifications of the U. S. Weather Bureau.)

(7) Output must be compatible with automatic data processing (NODC).

1.5200 FIXED MONITORING SYSTEMS.

1.5210 Fixed Monitoring System (shallow waters) (continuous or intermittent recording for storage and/or transmission upon interrogation). . . . . .(135)

Purpose: To provide for the collection, recording, storage, and/or transmission of meteorological and oceanographic data.

Specifications and requirements:

(1) For use in depths from 0 to 10 m.

(2) Designed to operate unattended from 24 hours to 1 month.

(3) Designed for continuous or intermittent recording and storage of data. (Transmission of data upon interrogation over distances of 100 miles would be optional.)

(4) Subsurface and surface sensors should meet the same requirements as for buoy system (Item 1.5110)

(5) Output must be compatible with automatic data processing (NODC).

1.5300 FISH COUNTING.

1.5310 Fish Census Device. . . . . (23)

A television camera or a photographic camera positioned forward of the codend of a trawl to observe the fish that pass through the net and an electric shocker at the mouth of the net to insure that each fish would pass through as it was overtaken.

1.5400 TAGS AND TAGGING EQUIPMENT

1.5410 Micro-miniature Sonic or Other Tags (for monitoring movements aquatic animals. . . . . .(7,013)

Purpose: To study the migration, spawning habits, distri-

bution, and behavior of animals, such as tuna, menhaden, salmon, herring, sardines, shrimp, seals, and sea lion.

Specifications and requirements:

(1) Small lightweight tags with minimum drag.

(2) Tags to be a self-contained, acoustic transducer having a detection range of 2 km. and a life of 10 to 30 days. (Present tags are too large, and lack longevity.)

1.5420 Environment Measuring Tags. . . . . .(17,502)

To register minima or maxima characteristics of environment, such as depth and temperature.

1.5430 Underwater Fish Tagger. . . . . (10)

A system that would permit television observation of fish in a trawl and which would shoot a single dart tag into the fish in target position when triggered from the ship.

1.5440 Fur Seal Tagger and Tags. . . . . (1)

A tagging device and suitable tag for fur seal studies. Such would inject a numbered and sealed radioactive slug coated with a biological marker (perhaps tetracycline) subcutaneously. It should be a magazine or hopper fed, gas operated, hand held, highly portable, gun-type instrument delivering a visually coded cylindrical slug approximately 2.5 by 17 mm.

1.5500 AUTOMATIC CHEMICAL ANALYSER. . . . . .(24)

Purpose: To provide an automatic system for chemical analysis of sea water aboard research vessels. (Such systems exist for laboratory use for other purposes, but none have been developed to analyse sea water samples at sea.)

Specifications and requirements:

(1) Automatic system to analyse and readout results.

(2) Provide quantitative analysis of the following: Inorganic phosphate, total phosphorus, oxygen, nitrite, nitrate, silicate, particulate iron, and certain vitamins.

(3) Accuracy: to customary laboratory accuracy.

1.5600 EXPENDABLE SYSTEMS.

1.5610 Bathythermograph. . . . . .(18,014 expendable units)

Purpose: A ship and/or airborne system is needed for making temperature-depth, and possibly other measurements while underway at high speeds utilizing expendable sensing units.

Possible method: Drop over side of ship a sensing vehicle with buoyed radio-telemetry unit which would remain on surface. After short interval, vehicle would sink at suitable rate through water sending information from depth and temperature sensor to telemetering buoy through gradually uncoiled wire or by sonic means. Signals from buoy would be received and recorded by system aboard ship or aircraft. Entire expendable unit would sink after pre-determined time. (System would be analogous to radiosounde for atmospheric data.)

Range and accuracy:

(1) Temperature: -2° to 35° C. $\pm 0.1^{\circ}$.

(2) Depth: 0 to 300 m. ± 1.

Specifications and requirements:

(1) Sinking rate: 1 m./sec. ± 0.2.

(2) Response time of sensors: 95% in 1 second.

(3) Range of radio transmission: 5 miles.

Cost of expendable units: Not to exceed $30.

1.5620 Thermographs. . . . . (316)

Purpose: There are several different types of thermographs available but there is a need for one which is quite small, light, and above all, inexpensive.

Range and accuracy: -2° to 30° C. 0.5°.

Specifications and requirements:

(1) Duration: 200 to 400 days.

(2) Depth: 0 to 400 m.

(If these units could be produced for less than $100 each, preferably less than $50, they could be thrown overboard on the fishing banks relying on fishermen to retrieve them for a suitable reward as with tagged fish.)

1.5700 TELEMETERING SYSTEM. . . . . .(20)

Develop a telemetering system which does not require an insulated cable. Multiplexing on the uninsulated trawl wire or improved sonic modulation might be investigated.

1.5800 THERMISTOR CHAIN (cheaper and lighter than existing models). . . . . .(12)

Specifications and requirements:

(1) Depth: 0 to 200 m.
(2) Operable to 15 knots.
(3) Standard depth sensing module at end of chain.
(4) Readout same as existing model.
(5) Range and accuracy: -2° to 35° C. $\pm 0.02^{\circ}$.

1.5900 CURRENT METER. . . . . .(47)

Purpose: To measure from shipboard, anchored buoy, or bottom mount the velocity of low currents.

Range and accuracy:

(1) Speed: 0 to 30 cm./sec. ± 1.
(2) Direction accurate to $\pm 5^{\circ}$.

Specifications and requirements:

(1) Two types:
  (a) Self-contained data storage.
  (b) Telemetering.
(2) For use singly or attached in series on a cable.
(3) Depth: To 12,000 m.
(4) Temperature: -2° to 45° C.

1.6000 FISHING GEAR.

1.6100 TRAWLS.

1.6110 Instruments for Gear Performance Studies.

Purpose: To provide foundation for analysis leading to design of most effective capturing devices.

Instruments to measure:

(1) Strain on netting and lines (immediate commercial application). . . . . (21)
(2) Vertical and horizontal net openings. . . . .(21)
(3) For hydrofoil and conventional trawl-door studies: angle of attack, angle of inclination, drag, and separation distance (lift). . . . . (19)
(4) Water velocity at the trawl. . . . . .(21)
(5) Speed over bottom. . . . . .(21)
(6) Total distance traveled. . . . . (20)
(7) Distance between points on trawl. . . . . (20)

Specifications and requirements:

(1) Instantaneous readout on shipboard through use of

trawl cables containing electrical conductors.
(2) Usable to depth of 2,500 meters.
(3) Should be resistant to extreme shock and vibration.
(4) Temperature range: -24° to 50° C. on deck and -2° to 35° C. when in use.
(5) Limits of measurements:
(a) Angles: 0 to 45° and 0 to 90°.
(b) Distance between points: 0 to 100 and 0 to 200 m.
(c) Speeds: 0 - 5, 0 - 10, and 0 - 15 knots.
(d) Tension: 0 to 3 kg., 0 to 25 kg., 0 to 250 kg., and 0 to 1,000 kg.

2.0000 LABORATORY EQUIPMENT.

2.1000 PLANKTON ANALYSIS.

2.1100 PLANKTON SEPARATOR AND COUNTER. . . . . .(21)
Purpose: A device to separate and count a sample of living and/or dead plankton organisms on the basis of size, density, and shape.

2.1200 EGG SEPARATOR AND COUNTER. . . . . (16)
Purpose: To enumerate on the basis of size the abundance of living and/or dead eggs of vertebrate or invertebrate animals in fresh or salt water samples.
Specifications and requirements:
(1) To accommodate a variety of egg sizes and shapes ranging in size from 0.1 to 10 mm. in maximum dimension.
(2) Capable of use on shipboard.

2.1300 SEDIMENT PARTICLE SIZE ANALYSER. . . . . (13)
Manufacture a device to analyse the sediment sample according to particle size distribution. (A prototype has been developed by Dr. T. J. Van Andle of Scripps Institution of Oceanography.)

2.1400 SORTING DEVICE FOR BENTHIC ORGANISMS. . . . . (15)
A device that could be used aboard a vessel for sorting bottom organisms from sediments. This device might incorporate an electrical current or high density fluids.

2.2000 MORPHOMETRIC ANALYSIS.

2.2100 ANNUAL RING RECORDER. . . . . (6)

Mollusk studies often require that large numbers of shells be read to locate annual rings and their distance from some reference point recorded. There is a need for a device which will be positioned by an operator but the distances will be automatically digitized and punched on cards.

2.2200 AUTOMATIC FISH MEASURING MACHINE. . . . . (43)

A device that would receive fish from a hopper, weigh and measure each one and give data readout preferably on magnetic tape, and may take scale sample in identifiable sequence to correspond with measurement.

REVIEWS

INTRODUCTION TO THE STUDY OF ANIMAL POPULATIONS. *By H. G. Andrewartha. University of Chicago Press, Chicago. 1961. 281 pp., figs., tables. $5.00.*

The title of this book is slightly misleading; one expects to learn about the structure and dynamics of populations, but instead is treated to a well-written, but rather disorganized, series of lecture notes on ecology. Unfortunately, most of the examples discussed are invertebrates, chiefly terrestrial forms. Possibly because of this fact, the methods given for estimating density and population size rely heavily on the use of quadrats, which are only occasionally useful for measuring fish populations. The author also discusses mark-recapture experiments, but the methods of analyses shown are not of the latest vintage.

The book contains many mathematical formulae which presuppose a high level of statistical training on the part of his readers. Despite this the author states: "If the 'patchiness' of the population follows a particular pattern it may be necessary to recognize this in placing the quadrats. The statisticians have developed a special technique which is called 'stratified sampling' to meet these requirements. But this is outside the scope of this book."

After discussing the Poisson series and the negative binomial for use when the variances are correlated with the means of the samples, he states that, "Larger samples will be needed for the same degree of accuracy when the variance is large than when it is small." This is in contradiction to the findings of Clyde C. Taylor (U. S. Fish and Wildl. Serv., Fish. Bull., 54(83): 145–166, 1953), who demonstrated in sampling heterogeneously distributed fish populations that: ". . . the variance may be reduced and the amount of information increased by decreasing the size of the observed mean, and it is suggested that this may be accomplished by reducing the length of tow and by reducing the size of the trawl net."

In the discussion of the dispersal of oyster and barnacle larvae he confuses turbulence with a laminar flow, saying (p. 51): "Certain barnacles and oysters that live in tidal rivers and estuaries have planktonic larvae whose behavior shows special adaptations which allow the population to persist in these places despite the fact that the net flow of water is outwards towards the ocean. Like the aphids, they make use of turbulence. The denser water near the bottom tends to have a net flow inland."

A strong attack is made on the theory of "density-dependent factors" in controlling population size. This is almost a mania with the author, yet surprisingly enough he has failed to cite much of the recent literature in support of the theory. He states (p. 169): "The 'theory' of 'density-dependent factors' has been the subject of a controversy in recent years. I shall suggest in section 9.34 that it should not be regarded as a scientific theory at all because its authors have underrated the empirical part of scientific method. This 'theory' is indeed more like dogma because it rests primarily on insight and deductive logic." He goes on (p. 181) with: "Scientific theory cannot be built directly from the conclusions of conceptual models. This is the chief mistake made by the adherents to the 'theory' of 'density-dependent factors.'" The proponents of the existence of density-dependent factors (for instance, Ricker, W. E., Stock and recruitment, J. Fish. Res. Bd. Canada, 11(5), 1954) will hardly be moved by the author's rather sweeping criticisms. Concerning experimental proof, the model of Ricker's reproduction curve has been shown to apply, for instance, to several decades of sockeye populations in the Karluk River system of Alaska (Rounsefell, G. A., U. S. Fish and Wildl. Serv., Fish. Bull., 58(130), 1958). Several "density-dependent" factors are shown to operate on this population.

The latter third of the book is a manual of experiments to be run by students as part of a laboratory course.

Because of the charming style, this book is well worth reading as an example of how usually boring details may be presented without losing the reader's attention.

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DESIGN OF FISHWAYS AND OTHER FISH FACILITIES. *By C. H. Clay. The Queen's Printer, Ottawa. 1961. 301 pp., figs., tables. $5.00.*

As a text for the university student studying advanced fishery techniques and for the advanced fishery worker who may have only occasional fish passage problems, this book is an excellent reference. It is of considerable value to the professional in this field as a compact, ready reference to details and dimensions of facilities with which it is assumed he is already familiar, since it covers a large proportion of existing water projects involving fish passage.

As would be the case with any book written currently in this rapidly developing field, some of the premises and formulae, such as that for computing fishway capacity, are already obsolete. The book is written in a straightforward fashion by an engineer closely associated with biologists in this field. The writer occasionally editorializes, reflecting popular opinions among biologists, but in general the book is quite factual. The author treats facilities for upstream-migrant fish in general, at natural obstructions, and at dams; discussing vertical-slot, denil, weir-and-pool, and lock-types of fishways. He discusses the problems involved: History, legal considerations, biological data, engineering surveys and field work, effects of dam operation, the importance of fishway entrances, various types of collection systems, and fishway exits. Also treated are weirs and barrier dams for counting upstream- and downstream-migrant fish, fish screens for the protection of downstream migrants, diverters of various types, artificial outlets for downstream migrants, artificial spawning channels, and devices for the capture of migrating adult and juvenile salmonids for experimental purposes, such as fish wheels and inclined-plane traps. What could be considered an omission is the lack of any reference to facilities, techniques, or devices for the electrical, mechanical, or photographic enumera-

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The Variability of Monthly Mean Sea Level at Six Stations in the Eastern North Pacific Ocean

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Abstract. On the basis of monthly mean data, the variation of observed sea level, the variation of sea level corrected for the static effect of atmospheric pressure, and the variation from regression of sea level on pressure are examined statistically for each month of the year at Honolulu, La Jolla, Los Angeles, San Francisco, Seattle, and Ketchikan. With increasing latitude, the variability of observed sea levels exhibits a greater seasonal change, a maximum variability occurring during the winter months. This result is due to a large extent to the effect of atmospheric pressure, which also has a greater variability during the winter months at the more northern stations. When the variance of sea level due to the direct static (inverted barometer) effect of atmospheric pressure and a further indirect effect associated with variance of atmospheric pressure is removed, the residual variance of sea level exhibits relatively small or no seasonal change and tends to have about the same value for all stations. The residual variance is interpreted as being representative of changes in the specific volume of the water column and thus representative also of the variability of the ocean currents in the vicinity of the station.

INTRODUCTION

he nontidal variation of sea level has received iderable attention, particularly within the few years. The points of view have been e varied, however. Variations of sea level their causes in the region off the Pacific t of the United States were discussed by *ond* [1939]. His demonstration of the close larity between weekly mean sea level at La a and the dynamic height anomalies from oceanographic cruises off the southern fornia coast in 1937 and 1938 is of particular rest. *Pattullo, Munk, Revelle, and Strong* 55] examined the mean annual cycle of sea l as related to the mean steric levels and to water budget of the world oceans. *Stommel* 58] used the relative difference in sea level n Havana to Cat Key and Key West as an cation of month-to-month fluctuations in Florida current. *Roden* [1960] employed correlation techniques to describe the variity of sea level and to show its relation to nges in air pressure, sea surface temperature, wind. His study placed emphasis upon exnation of the statistical predictability of sea l. *Lisitzin and Pattullo* [1961] compared sea l in the Pacific Ocean as recorded during the Y with an *isostatic* level computed from changes in atmospheric pressure and the specific volume of the water column.

The interest of the Bureau of Commercial Fisheries Biological Laboratory, Stanford, in changes in sea level lies in the possibility of reconstructing a history of changes of the oceanographic environment as related to changes in abundance and availability of commercial fish. Changes in sea level reflect, in part, changes in the density structure of the water column and the forces exerted upon it. Unfortunately, the sea level data are restricted to coastal and island stations. However, for a study of historical changes of oceanographic conditions, these data will supplement sea surface temperature data taken by merchant and naval ships which have relatively long-term continuity in space as well as in time, but which reflect changes only in conditions at the sea surface or very near the surface.

In the study reported here we examined the variability of monthly mean sea level as related to time of year. It is shown that the variability exhibits a pronounced seasonal change at certain locations. Such an effect is not apparent from the study by Roden, since the autocorrelation approach produces an average variance for the entire period of record. It is believed that a

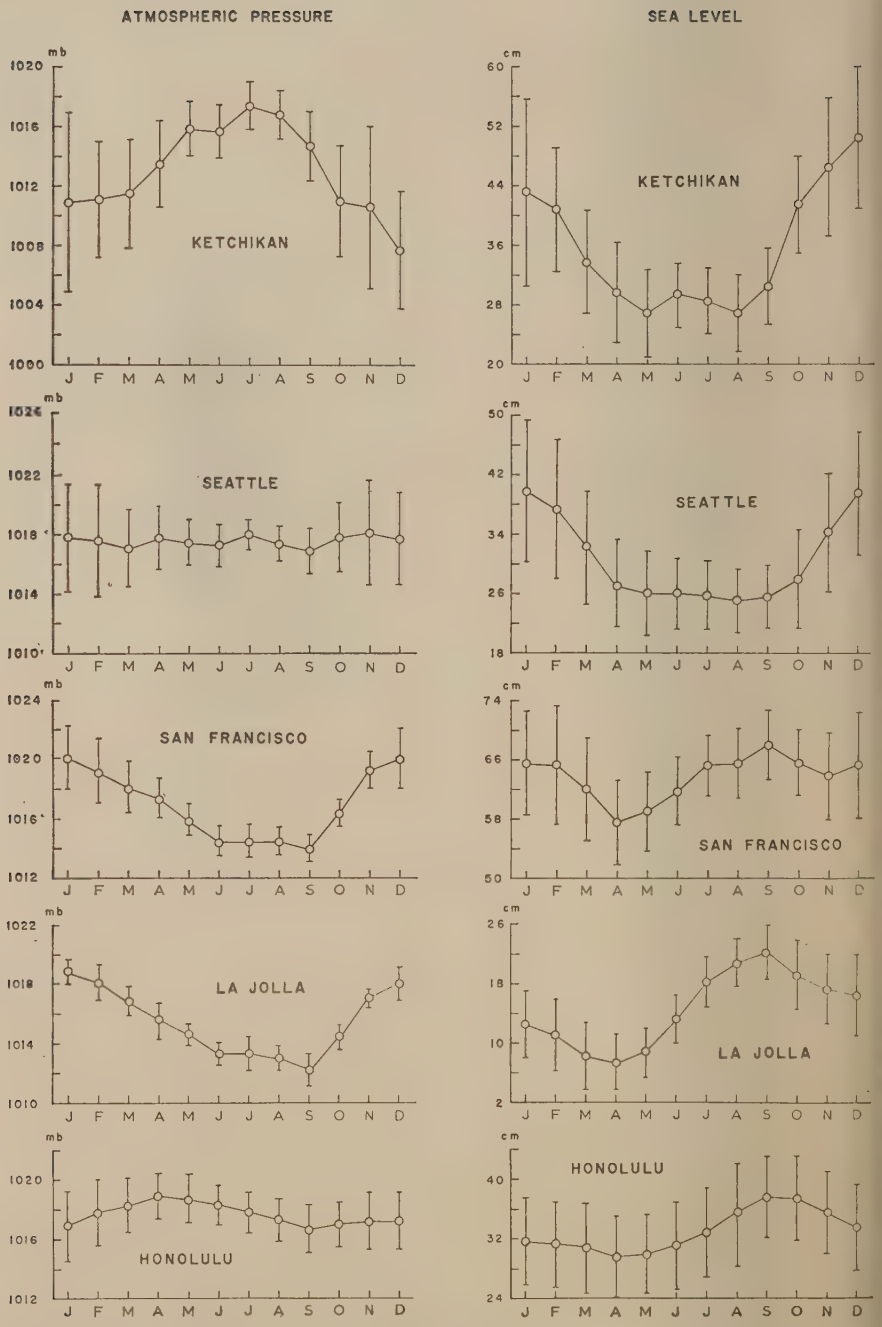

Fig. 1. Mean annual cycle and monthly variability of atmospheric pressure (millibars) and sea level (centimeters). Vertical bars represent range of ±1 standard deviation about the mean monthly value. Sea level heights are above arbitrary datum at each station.

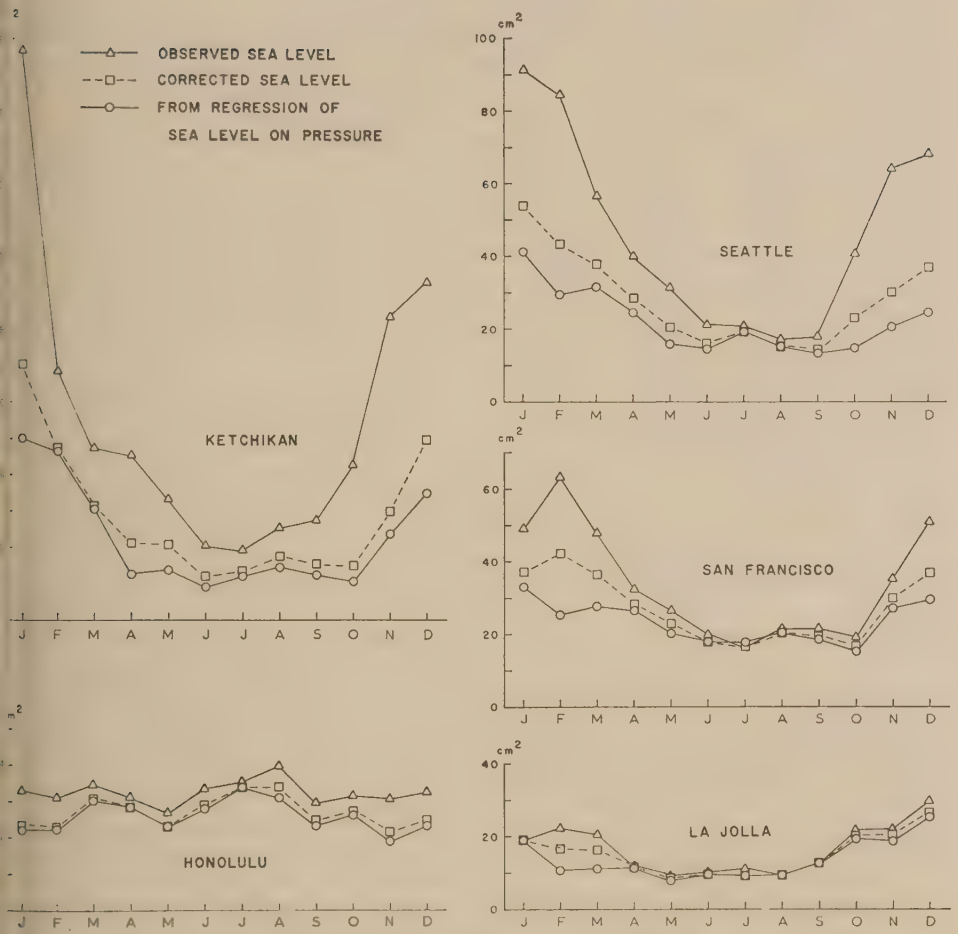

Fig. 2. Monthly variance (cm²) of observed sea level, of corrected sea level, and from regression of sea level on pressure.

ly of the variability by month or season of- a better possibility for an understanding of mechanisms involved.

he relation of sea level variations to vari- ity in atmospheric pressure was examined. rding to the 'inverted barometer' concept, level will be depressed very nearly 1 cm for ise of 1 mb of atmospheric pressure. It is wn that this static effect accounts for only ortion of the variability of sea level, as in- ted by previous authors, but that the pro- tion depends upon the month of the year. nalyses by regression and correlation tech- ues show that there is an additional variation ea level that is also correlated to the change in atmospheric pressure, as an indirect effect, which depends again upon time of year. Finally, the residual variation of sea level, that which remains after the variations related to both the static and indirect effects of atmospheric pressure have been removed, is described and is postulated to represent changes in the specific volume of the water column.

Data

Monthly mean sea level data through 1957 for stations in the eastern North Pacific Ocean were obtained from the U. S. Coast and Geodetic Survey. The six stations selected for geographic range and the availability of suitably long rec-

ords were: Honolulu (53 years), La Jolla (31 years), Los Angeles (34 years), San Francisco (59 years), Seattle (59 years), and Ketchikan (39 years).

Monthly mean atmospheric pressure data were obtained from the U. S. Weather Bureau station nearest each tide-gage location. Because of changes in station location, these were adjusted to sea level pressure. At Ketchikan, pressure records were available for the period 1930 through 1947[1] and from Annette Island after 1947. This limited the period of comparison of sea level and pressure to 28 years at Ketchikan. San Diego pressure data were used for comparison with sea level data at La Jolla.

Monthly mean sea level data are computed by the Coast and Geodetic Survey from 24 readings per day at hourly intervals and are given to the nearest 0.01 foot (0.3 cm). Monthly mean pressure data are computed by the Weather Bureau from the four synoptic observations daily and are given to 0.01 inch of mercury (0.3 mb).

Analysis

For each station a linear regression analysis of sea level on atmospheric pressure was made for each month. Results are shown in Tables 1 to 6 for each of the six stations. Columns of each table are as follows.

- $\bar{p}$ = mean atmospheric pressure at sea level, millibars.
- s_p = standard deviation of pressure, millibars.
- $\bar{l}$ = mean sea level, centimeters. (Height above arbitrary datum plane.)
- s_l = standard deviation of sea level.
- s_c = standard deviation of 'corrected' sea level (explained below).
- $s_{l.p}$ = standard deviation from regression of sea level on pressure.
- b = regression coefficient of sea level on pressure.
- r = correlation coefficient of sea level and pressure.

All the above terms conform to those for standard regression-correlation analysis of sea level and pressure except s_c. $\bar{p}$ and $\bar{l}$ are the long-t m means of the monthly values, and the stand d deviations measure the variability of anoma s of the monthly values from the long-term m n for the given month.

The 'corrected' sea level was calculated to count for the static effect of atmospheric p s sure by applying a correction of 1 cm in l level for 1 mb deviation of atmospheric pres e from its long-term mean monthly value. (e of the more accurate value of 0.995 cm is warranted by the data.) The standard devia n of corrected sea level, s_c, was then computed r these values.

The 5 per cent level of significance for r m be determined for each station by use of th t test. A table of correlation coefficients at th 5 and 1 per cent levels of significance is given y *Snedecor* [1956]. In Tables 1 to 6 the values f r which are significant at the 5 per cent level e indicated in boldface type. We would anticip e that, because of the static effect of pressure n sea level, the correlation would be signific , and generally it is. There are a few exceptio , however, occurring mainly in summer mont

With regard to the regression coefficient, b, we note that if the static effect of pressure n sea level were the only relation between s level and pressure, the regression coeffici t would be equal to -1. The t test was also u d to determine whether the regression coefficie , b, was different from -1 at the 5 per cent le l of significance. Those cases with a signific t difference are designated in the tables in bo face type. The difference between s_c and also serves to indicate the extent of an indi t relation between sea level and pressure occurr g in addition to the direct static effect.

The mean annual cycles and the stand d deviations for each month of the atmosph e pressure and the sea level are shown in Fig e 1 for each station except Los Angeles, wh h is very similar to La Jolla. The vertical through the mean value for each month rep - sents the range of ± 1 standard deviation of e monthly anomalies from the mean. Note tha 2 cm for sea level occupies the same distance n the vertical scale as 1 mb for atmospheric p - sure.

The seasonal oscillation of sea level and s relation to atmospheric pressure have been - scribed, on the basis of *long-term means*,

[1] Mean sea level pressure data for 1930 through 1940 were obtained from *Climatological Data, Alaska,* published by the U. S. Weather Bureau.

TABLE 1. Results of a 53-Year Statistical Analysis of Monthly Mean Atmospheric Pressure and Sea Level at Honolulu

h	$\bar{p}$, mb	s_p, mb	$\bar{l}$, cm	s_l, cm	s_c, cm	$s_{l \cdot p}$, cm	r^*	b,* cm/mb
J.	1016.9	2.3	31.7	5.8	4.8	4.7	**−.58**	**−1.5**
F.	1017.8	2.2	31.3	5.6	4.8	4.7	**−.54**	**−1.3**
M.	1018.3	1.8	30.7	5.9	5.6	5.6	**−.36**	**−1.2**
A.	1018.9	1.5	29.6	5.6	5.4	5.4	**−.31**	**−1.2**
My	1018.7	1.6	29.9	5.2	4.9	4.8	**−.38**	**−1.2**
Je	1018.3	1.3	31.0	5.8	5.3	5.3	**−.42**	**−1.8**
J.	1017.8	1.3	32.9	5.9	5.8	5.8	−.24	−1.1
A.	1017.3	1.4	35.7	6.3	5.8	5.6	**−.48**	**−2.2**
St.	1016.7	1.6	37.6	5.4	4.9	4.8	**−.48**	**−1.7**
O.	1017.0	1.5	37.4	5.6	5.2	5.2	**−.41**	**−1.5**
N.	1017.2	1.9	35.5	5.5	4.6	4.4	**−.63**	**−1.8**
D.	1017.2	1.9	33.5	5.7	5.0	4.8	**−.53**	**−1.6**

Boldface type denotes:

r significantly different from 0 at the 5 per cent level, $|r| = 0.27$.
b significantly different from -1.0 at the 5 per cent level.

ullo, et al. [1955]. They found that the re-led change in sea level in low and tem-te latitudes agreed well with steric changes, is, those computed from the change in ific volume of the water column. Atmos-ric pressure effects were found to account only a small part of the recorded changes in level. However, *Lisitzin and Pattullo* [1961] d that, for the shorter period of the IGY the region north of latitude 40°N, atmos-ric pressure effects were the predominant in-nce on seasonal changes in sea level. In Fig-s 1 to 6 the seasonal curves of mean sea level e not been corrected for the mean seasonal nge in atmospheric pressure.

The purpose here is to examine the variability monthly anomalies from the long-term mean the given month and the seasonal change in s variability. The essential features, as seen m Figure 1 and Tables 1 to 6, which show variability of atmospheric pressure and sea el and their relation to each other, are set th below. (See also Fig. 2 for change in vari-e of sea level with season.)

Honolulu. 1. The variability of atmospheric ssure is essentially the same for each month oughout the year.

2. The variability of sea level is essentially same throughout the year, and the standard viation for any month is about the same as range of the mean annual cycle.

3. The correlation between sea level and pressure is significant for all months except July, but is not large (Table 1).

4. The slope of the regression is consistently greater than −1, but the amount by which it is greater is generally not significant because of the low correlation (Table 1). The relation between variability of sea level and that of pressure appears, therefore, to be confined essentially to the static effect.

La Jolla and Los Angeles. 1. The variability of atmospheric pressure is essentially the same throughout the year, and it is less than that for any of the other stations examined.

2. The variability of sea level is less than that for Honolulu, and a slight minimum in variability occurs during the summer months. One standard deviation is much less than the range of the annual mean cycle.

3. The correlation of sea level and pressure is quite variable and without significance in 6 of the 12 months (Tables 2 and 3).

San Francisco. 1. A noticeable seasonal change in variability of atmospheric pressure occurs, the standard deviation for the winter months being more than double that for the summer months.

2. Variability of sea level is somewhat larger than for the stations previously discussed, particularly for the months December through March when the standard deviation is about double that for summer months. The standard

TABLE 2. Results of a 31-Year Statistical Analysis of Monthly Mean Atmospheric Pressure and Sea Level at La Jolla

Month	$\bar{p}$, mb	s_p, mb	$\bar{l}$, cm	s_l, cm	s_c, cm	$s_{l.p}$, cm	r*	b,* c
Jan.	1018.7	0.9	12.5	4.4	4.4	4.4	−.18	−
Feb.	1018.1	1.2	11.0	4.8	4.1	3.3	**−.74**	−
Mar.	1016.8	0.9	8.2	4.5	4.0	3.4	**−.69**	−
Apr.	1015.6	1.1	7.3	3.5	3.4	3.4	−.25	−
May	1014.6	0.7	8.9	3.0	2.9	2.8	**−.39**	−
June	1013.3	0.7	13.1	3.2	3.1	3.1	−.23	−
July	1013.3	1.1	18.2	3.3	3.1	3.1	**−.40**	−
Aug.	1013.0	0.8	20.7	3.1	3.2	3.1	0.0	
Sept.	1012.2	1.0	22.2	3.6	3.7	3.6	−.09	−
Oct.	1014.4	0.8	19.1	4.6	4.5	4.4	−.33	−
Nov.	1017.0	0.6	17.3	4.7	4.5	4.4	**−.39**	−
Dec.	1018.0	1.1	16.4	5.4	5.2	5.0	**−.40**	−

* Boldface type denotes:
r significantly different from 0 at the 5 per cent level, $|r| = 0.36$.
b significantly different from -1 at the 5 per cent level.

TABLE 3. Results of a 34-Year Statistical Analysis of Monthly Mean Atmospheric Pressure and Sea Level at Los Angeles

Month	$\bar{p}$, mb	s_p, mb	$\bar{l}$, cm	s_l, cm	s_c, cm	$s_{l.p}$, cm	r*	b,* c
Jan.	1018.7	1.1	16.7	4.1	4.1	4.1	−.21	−
Feb.	1018.0	1.4	14.9	4.9	4.1	3.4	**−.72**	−
Mar.	1016.5	1.0	12.2	4.4	3.9	3.3	**−.66**	−
Apr.	1015.4	0.9	10.9	2.8	2.5	2.5	**−.47**	−
May	1014.3	0.7	13.1	3.2	2.9	2.5	**−.65**	−
June	1013.0	0.7	17.1	3.2	3.2	3.2	−.07	−
July	1013.1	1.0	21.8	3.4	3.4	3.4	−.24	−
Aug.	1013.0	0.9	23.8	3.2	3.2	3.2	−.17	−
Sept.	1012.0	0.8	25.2	4.0	4.1	4.1	.06	
Oct.	1014.5	0.7	22.6	4.6	4.3	4.0	**−.51**	−
Nov.	1017.3	0.8	20.5	4.6	4.4	4.4	**−.34**	−
Dec.	1018.2	1.2	19.6	5.0	4.4	4.1	**−.60**	−

* Boldface type denotes:
r significantly different from 0 at the 5 per cent level, $|r| = 0.34$.
b significantly different from -1.0 at the 5 per cent level.

deviation for summer months is about one-half the range of the mean annual cycle.

3. The correlation between sea level and pressure changes fairly regularly from a high level in winter to an insignificant level in July and August (Table 4).

4. The slope of the regression is significantly greater than -1 for the entire period of October through March (Table 4).

Seattle. 1. Although there is practically no annual cycle to the mean atmospheric pressure, the variability of pressure changes appreciably with season. The minimum values of varia which are reached during the summer m are about the same as those for Honolul San Francisco and only slightly larger than for La Jolla and Los Angeles.

2. The mean annual cycle of sea level reversed from the previous stations, the maxi height being reached in the winter rather in the late summer, but the variability is greatest in winter and least in summer. minimum values of variability reached d the summer are no greater than those fo

TABLE 4. Results of a 59-Year Statistical Analysis of Monthly Mean Atmospheric Pressure and Sea Level at San Francisco

	$\bar{p}$, mb	s_p, mb	$\bar{l}$, cm	s_l, cm	s_e, cm	$s_{l.p}$, cm	r*	b,* cm/mb
	1020.1	2.1	65.6	7.0	6.1	5.7	**−.59**	**−2.0**
	1019.2	2.1	65.3	8.0	6.5	5.0	**−.78**	**−2.9**
	1018.1	1.7	62.0	6.9	6.0	5.3	**−.66**	**−2.7**
	1017.4	1.3	57.6	5.7	5.3	5.2	**−.44**	−1.9
	1015.9	1.0	59.0	5.2	4.8	4.5	**−.51**	**−2.7**
	1014.5	1.0	61.7	4.5	4.3	4.3	**−.34**	−1.4
	1014.5	1.1	65.2	4.1	4.1	4.1	−.12	−0.4
	1014.5	0.9	65.5	4.6	4.5	4.5	−.24	−1.2
	1014.0	0.9	67.9	4.7	4.4	4.3	**−.39**	−1.9
	1016.4	0.9	65.6	4.4	4.1	3.9	**−.48**	**−2.4**
	1019.3	1.2	63.8	5.9	5.5	5.2	**−.49**	**−2.3**
	1020.1	2.0	65.2	7.1	6.1	5.4	**−.66**	**−2.3**

*Boldface type denotes:

r significantly different from 0 at the 5 per cent level, $|r| = 0.25$.
b significantly different from −1 at the 5 per cent level.

TABLE 5. Results of a 59-Year Statistical Analysis of Monthly Mean Atmospheric Pressure and Sea Level at Seattle

	$\bar{p}$, mb	s_p, mb	$\bar{l}$, cm	s_l, cm	s_e, cm	$s_{l.p}$, cm	r*	b,* cm/mb
	1017.8	3.6	39.8	9.5	7.3	6.4	**−.74**	**−2.0**
	1017.6	3.8	37.3	9.2	6.6	5.4	**−.81**	**−2.0**
	1017.1	2.6	32.2	7.6	6.2	5.6	**−.67**	**−1.9**
	1017.8	2.1	27.0	6.3	5.3	4.9	**−.63**	**−1.9**
	1017.5	1.5	26.0	5.6	4.5	4.0	**−.71**	**−2.6**
	1017.3	1.4	26.0	4.6	4.0	3.8	**−.58**	**−1.9**
	1018.0	1.0	25.8	4.5	4.4	4.4	**−.26**	−1.2
	1017.4	1.1	25.0	4.2	4.0	3.9	**−.37**	−1.5
	1016.9	1.5	25.7	4.2	3.8	3.7	**−.51**	−1.5
	1017.8	2.3	27.9	6.4	4.8	3.8	**−.80**	**−2.2**
	1018.1	3.5	34.2	8.0	5.5	4.5	**−.83**	**−1.9**
	1017.7	3.1	39.6	8.2	6.1	4.9	**−.81**	**−2.1**

Boldface type denotes:

r significantly different from 0 at the 5 per cent level, $|r| = 0.25$.
b significantly different from −1.0 at the 5 per cent level.

cisco. Summer standard deviations are t one-third the range of the mean annual .

The correlation between pressure and sea is significant for all months and is relatively . between −0.67 and −0.83, from October igh March (Table 5).

The slope of the regression is significantly ter than −1.0 for all months except July, ust, and September (Table 5).

etchikan. 1. The mean annual cycle of atpheric pressure reaches a maximum in sumat Ketchikan. The variability, however, as for the other stations, is greatest in the winter months and least during the summer months.

2. As at Seattle, the mean annual cycle of sea level reaches its minimum in the summer. The variability, which is larger in winter, becomes small in summer, when it is very nearly the same as that for Seattle and San Francisco. One standard deviation in summer is about one-fourth the range of the mean annual cycle.

3. The correlation of atmospheric pressure and sea level is −0.75 or better for all months except February, March, July, and August. (Table 6). The somewhat low values for Feb-

TABLE 6. Results of a 28-Year Statistical Analysis of Monthly Mean Atmospheric Pressure and Sea Level at Ketchikan

Month	$\bar{p}$, mb	s_p, mb	$\bar{l}$, cm	s_l, cm	s_c, cm	$s_{l.p}$, cm	r*	b,* cm
Jan.	1010.9	6.0	43.1	12.5	8.4	7.1	**−.83**	**−7**
Feb.	1011.1	3.9	38.8	8.3	6.9	6.8	**−.59**	**−2**
Mar.	1011.5	3.6	3.37	6.9	5.6	5.5	**−.62**	**−2**
Apr.	1013.5	2.9	29.6	6.7	4.6	3.6	**−.85**	**−3**
May	1015.9	1.8	26.8	5.8	4.6	3.7	**−.77**	**−4**
June	1015.7	1.8	29.4	4.5	3.4	3.0	**−.75**	**−9**
July	1017.4	1.6	28.5	4.4	3.7	3.4	**−.64**	**−3**
Aug.	1016.8	1.6	26.8	5.1	4.2	3.8	**−.68**	**−2**
Sept.	1014.7	2.3	30.4	5.1	3.9	3.5	**−.76**	**−7**
Oct.	1011.0	3.7	41.4	6.5	3.8	3.1	**−.87**	**−5**
Nov.	1010.6	5.4	46.4	9.2	5.5	4.9	**−.85**	**−4**
Dec.	1007.7	3.9	50.4	9.6	7.0	5.9	**−.80**	**−7**

* Boldface type denotes:

r significantly different from 0 at the 5 per cent level, $|r| = 0.37$.
b significantly different from -1.0 at the 5 per cent level.

ruary and March do not seem to fit the pattern, but are unexplained at present.

4. The slope of the regression is significantly greater than −1.0 for all months except February, March, and July (Table 6).

Discussion

Averaged throughout the year, the monthly variability of sea level along the continental coast increases with latitude, as indicated by previous authors. However, certain features of the variability become apparent from the month-by-month analysis. It indicates that the amount of increase depends greatly upon season. Variability increases with latitude during the months November through March, but increases very little with latitude during the months May through September. This increase in variability is in large part associated with an increase in variability of atmospheric pressure from low to mid-latitude which occurs in the winter half of the year.

At all stations except Honolulu there is a contribution in some months to the inverse relation between variations in atmospheric pressure and in sea level in addition to the static effect; that is, the absolute value of the regression coefficient is larger than 1. Although the confidence limits on regression coefficients are fairly wide, a pattern emerges for those values which are significantly different at the 5 per cent level from −1. First, all significantly different values indicate a greater slope than −1 for the line of regression. At the low-latitude stations these significantly different values appear for only winter months. With increasing latitude of station, the significantly different values appear for more months, but least frequently for summer months.

This additional effect is probably only indirectly related to pressure and may occur because the five stations exhibiting this property are located on the west coast.[2] Generally the pattern of winds during the winter half of the year is such that a negative anomaly of atmospheric pressure at the stations is associated with stronger southerly to westerly winds adjacent to the coast. The increase in sea level related to lower pressure might thus be due, at least partially, to a piling up of water along the coast by the winds, that is, an increase in the amount of mass in the water column, called

[2] I am indebted to Mr. Bernard Zetler, Coast and Geodetic Survey, who has called my attention to a 'Report of Meteorological Effects on Tides, from Observations by Prof. Wm. Ferrel,' appendix 6 to the *Report of the Superintendent of U. S. Coast Survey for the Year 1871*. Professor Ferrel's data on departures of sea level from predicted high and low tides for Boston indicate that the regression of sea level on pressure for that location would be about −0.5. He further mentions a few studies at European ports giving the following coefficients: Brest, −1.0; Liverpool, −0.8; London, −0.5.

wind effect by *Groves* [1957]. However, monthly averages are being considered, a change in winds would more probably ce a change in the *steric level*, that is, as ed by *Pattullo, et al.* [1955], a change in fic volume (and height) of the water col- without a change in the total mass. Since ocal wind effect and change in steric level both influenced by wind (gradient of pres- rather than pressure), a further study of variability of sea level as related to anoma- of geostrophic wind is certainly warranted.

ne effect of progressively eliminating the parts of the variation of sea level related pressure can be seen in Figure 2 for each on except Los Angeles, which is very similar La Jolla. The triangles represent the ob- ed variance of sea level (cm^2) for each th. These again show that the monthly var- on differs with season and that the range maximum variability in winter to mini- n variability in summer increases with lati- .

he squares indicate the variance of corrected level. It is seen that correction for the static t of air pressure generally decreases the ation, the decrease being as much as 50 per in some months in the winter half of the r at Seattle and Ketchikan.

The circles give the variance from regression ea level on pressure. It should be noted here t, even though the regression coefficient was n about −2.0, the change from variance of ected sea level to variance from regression enerally small when compared with change n variance of observed sea level to variance corrected sea level. However, when the in- ct effect of pressure is removed in addition he static effect the residual variation tends ther toward uniformity with season. The uni- mity indicates that the factors causing the dual variation tend to be similar in both mer and winter, although they are still ewhat greater in magnitude in winter ex- t at Honolulu. Further, there is little differ- e between stations in the amount of the dual variation. The causes of the residual iation in sea level may thus be similar re- lless of latitude, as well as varying little with son.

At the three southern stations, and for 7 nths at San Francisco, the residual variation in sea level differs little from the variation of observed sea level, and *Lisitzin and Pattullo* [1961] have shown from a study of Pacific sea level data taken during the IGY that, for latitudes less than 40°, changes in steric level agree well with changes in sea level. Thus the residual variation at all stations probably represents the variation in steric level (on a monthly mean basis).

The variability in the steric level at a coastal station probably reflects, in turn, the variability in the ocean current along the coast. It may be inferred from the residual variation of sea level that appreciable changes in current along the west coast of North America have occurred during the same month of different years. The year-to-year difference in the same month may be as great as the mean seasonal change in current.

The reasoning regarding the relation between residual variation, variation of steric level, and changes in current is based upon meager evidence. Also unresolved is the question whether the effect on sea level indirectly related to atmospheric pressure, even though it is relatively small, is also due to a change in steric level. Particularly lacking for a solution to these problems are relatively long time-series of oceanographic data from which to compute steric levels in the neighborhood of the tide stations. Such data from numerous locations are certainly required before it will be possible to compute the errors attendant to a quantitative evaluation of changes in ocean current from changes in sea level.

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WHITE SHARKS, *CARCHARODON CARCHARIAS*, IN MAINE, 1959–1960.—Rumors of the appearance of a white or man-eater shark, *Carcharodon carcharias* (Linnaeus), arouses considerable public interest, and even alarm, for this species has earned the reputation of being dangerous to man. During 1960, there were numerous newspaper accounts of sharks being seen inshore along various northeastern U. S. bathing beaches. These news releases focussed attention again on the possible occurrence of the white shark in that region.

This paper presents 12 records of white sharks caught along the Maine coast in 1959 and 1960 (Table 1). The eight captures in 1960 represent the greatest number recorded for any one year along the U. S. Atlantic coast. This number can be attributed in part to the publicity given to shark captures in 1960, for newspaper accounts guided me to several sharks. I had also the cooperation of five sport fishermen who in previous years had landed white sharks without my knowledge. Nine of the 12 sharks were caught by sport fishermen.

Few New England fishermen, either sport or commercial, have had an interest in identifying the various sharks, consequently it was not surprising to learn that they have seldom distinguished the white shark from the porbeagle, *Lamna nasus* (Bonnaterre), and the mako, *Isurus oxyrinchus* Rafinesque. All three species may be called mackerel sharks or makos. A large white shark has often been called a mud shark or cow shark—names it shares with the basking shark, *Cetorhinus maximus* (Gunnerus). As a result of this confused situation, identification of most Maine sharks is dependent upon an examination of the fish itself, a photograph, or teeth, rather than the fishermen's reports.

After having the head, tail, and viscera removed, Maine white sharks, like Maine porbeagles, are often shipped to the Boston or New York fresh fish markets. These markets can absorb only a few sharks at a time, so the price may range from 1 to 10 cents per pound, depending upon the supply. Commercial gillnetters operating out of Portland, Maine, land an occasional white shark; however, a large specimen is usually cut free from the nets because of the difficulty in getting it aboard.

The white shark is not rare in northern New England waters from Cape Cod northward. For the 30-year period, 1931 to 1960, there are published records for 17 specimens (Schroeder, 1938, *Copeia:46*, and 1939, *Copeia:48;* Bigelow and Schroeder, 1953, *Fish. Bull. U. S. Fish & Wildl. Serv. 53: 26–7;* Scattergood and Coffin, 1957, *Copeia: 155;* Scattergood and Goggins, 1958, *Maine Field Nat. 14:40*; Bigelow and Schroeder, 1958, *Copeia:54–5;* Scattergood, 1959, *Maine Field Nat. 15:107*). To these can be added the 12 new Maine shark records, making a total of 29. On a monthly basis, 1 has been caught in June; 8 in July; 13 in August; 2 in

TABLE 1. WHITE SHARKS, *Carcharodon carcharias*, TAKEN IN MAINE DURING 1959 AND 1960

Location of Capture	Date	Length (feet)	Sex	Gear	Fisherman
Lincoln County, Pumpkin Rock	7/23/59	7.7	M	Harpoon	Pat Elderkin
" " off Boothbay Harbor	7/23/59	6.3	M	Harpoon	Lou Garcelon
Knox County, Saddleback Ledge	8/6/59	12.8	F	Harpoon	U. S. Coast Guard
" " Mark Island	August, 1959	7.5	–	Harpoon	Harry Goodridge
" " " "	7/17/60	11.2	–	Harpoon	" "
Lincoln County, off Boothbay Harbor	7/18/60	6.5[1]	–	Trawl line	Lou Garcelon
Knox County, off Camden	First week of August, 1960	9.0[2]	–	Harpoon	Lincoln Davis
" " Mark Island	8/10/60	10.9	M	Harpoon	Harry Goodridge
Lincoln County, New Harbor	8/14/60	7.5[1]	–	Harpoon	Sam Morton
Cumberland County, 8 mi. SE of Cape Elizabeth	8/23/60	6.0	–	Gill net	Ole Mikkelsen
Lincoln County, 11 mi. S of Damariscove Whistler	8/31/60	7.5	F	Harpoon	Pat Elderkin
Hancock County, Isle au Haut Thorofare	Last week of August, 1960	10.5[1]	M	Harpoon	Reggie Greenlaw

[1] Estimated by fishermen.
[2] Estimated from a photograph.

September; 3 in October; and 2 in November. It appears that this shark is most common during the summer months. While this is undoubtedly true, the monthly totals are affected by the fishing activities. For example, sport fishermen are most active during the summer, and most pound nets and floating traps operate mainly during May to October in Massachusetts and June to September in Maine. The chances of capturing Maine white sharks are best during July and August when boating and fishing are at a peak, and this is the period when 82 per cent of the Maine white sharks records have been made.

Of the 29 white sharks, 1 was 3 feet long; 1 was 4.8 feet; 11 ranged from 6.0 to 7.9 feet; 4 from 8.0 to 9.9 feet; 6 from 10.0 to 11.9 feet; 3 from 12.0 to 13.9 feet; 2 from 14.0 to 15.9 feet; and 1 was 17.5 feet. Bigelow and Schroeder (1948, *Fishes of the Western North Atlantic, I, part 1:138*) believed that maturity is reached at 13 to 14 feet; consequently, it appears that most northern New England white sharks are immature. However, this conclusion must be tempered by the realization that fishermen may avoid molesting the large specimens that would be difficult to capture and bring aboard.

Some further information on feeding habits of the shark was gathered. Of the five sharks I examined whole, four had empty stomachs. The 23 July 1959 specimen contained the partially digested remains of two harbor seals, one of which was Basil, the two-month-old pet of Rockport, Maine, sport fisherman Harry Goodridge, who harpooned the 10.9-foot shark after it bit in two and devoured Basil as he was swimming near Goodridge's boat. Stonington, Maine sport fisherman Reginald Greenlaw told me that the 10.5-foot shark he harpooned in the last week of August 1960 had the remains of a single seal in its stomach.—LESLIE W. SCATTERGOOD, *U. S. Fish and Wildlife Service, Bureau of Commerical Fisheries, Washington, D. C.*

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FIRST RECORD OF MAKO, *ISURUS OXYRINCHUS*, IN MAINE WATERS.—The capture of mako sharks has been reported repeatedly along the Maine coast; however, there have been no published authentic records of their occurrence north of Cape Cod (Bigelow and Schroeder, 1948, *Mem. Sears Found. Mar. Res. 1:130*). Mako is a common name applied in Maine to *Lamna nasus, Carcharodon carcharias,* and even *Prionace glauca.* Of the many "mako" landings that I have investigated in Maine, only one was *Isurus oxyrinchus.* This was a specimen with an estimated weight of 400 to 450 pounds harpooned July, 1957, off Boon Island, York County, by Joe Kashmere and Walter Donnell, commercial fishermen of York Harbor. The dressed shark was sent to the New York market. Maine Sea and Shore Fisheries Warden Thomas Flaherty provided me with these data and the several teeth that enabled me to identify the shark.

With this identification, the western Atlantic range of *I. oxyrinchus* is extended northwards to the southeastern coast of Maine. According to L. R. Day of the Fisheries Research Board of Canada, St. Andrews, N. B., there are no Canadian Atlantic records of the mako.—LESLIE W. SCATTERGOOD, *United States Fish and Wildlife Service, Bureau of Commercial Fisheries, Washington, D. C.*

The Occurrence of the Longjaw Cisco, *Leucichthys alpenae*, in Lake Erie[1]

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ABSTRACT

The longjaw cisco, *Leucichthys alpenae*, is shown to be a species new to the Lake Erie fauna. The taxonomic work on Lake Erie ciscoes is reviewed. Thirty three specimens of *L. alpenae* taken in 1946, 1947 and 1957 are compared morphometrically with *Leucichthys artedi* of Lake Erie, the only other cisco species in the lake. *L. alpenae* has a longer and deeper head, longer maxillary and fewer gill rakers. *L. alpenae* is more distinct from *L. artedi* in Lake Huron than in Lake Erie. The rate of growth of *L. alpenae* in Lake Erie compares favourably with that in Lake Michigan.

New distribution records of species endemic to the Great Lakes are rare. It is not too surprising, however, that such a discovery should occur among the coregonids—the most abundantly represented family in the Great Lakes and one comprised of fish of apparently such recent origin (Smith, 1957) that the species are difficult to describe, and often even more difficult to recognize for the untrained observer.

A recent new record was based on the discovery of the pygmy whitefish, *Prosopium coulteri*, in Lake Superior in 1952 (Eschmeyer and Bailey, 1955). Its small size, and occurrence in depths of 10–50 fathoms, contributed to the absence of this species from commercial gill and impounding nets designed to capture only large fish, and from the shore seines employed in fishery surveys. Some individuals may have been taken in small-mesh gill nets used to catch bait for lake trout hooks, or in seines hauled for lake herring, but to the untrained eye of the fisherman they may have appeared to be only young of their closest relative, *Prosopium cylindraceum*.

Circumstances were similar in the recent discovery of the shortnose cisco, *Leucichthys reighardi*, in Lake Huron[2] and longjaw cisco, *L. alpenae*, in Lake Erie. Both of these species undoubtedly have been taken by commercial fishermen but in small numbers for they are most common in areas seldom fished with

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[2]The first record of the shortnose cisco in Lake Huron was made by biologists of the research vessel *Cisco* during a general fishery survey by the U. S. Bureau of Commercial Fisheries of Saginaw Bay and southern Lake Huron in 1956.

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gear best suited for their capture. Indeed, the fishermen at Port Dover, Ontario have long been aware of the presence of a deepwater cisco in the "deep hole" of eastern Lake Erie. They were poorly represented in commercial landings however, because they were not taken in abundance except near the spawning grounds which were visited during the stormy period in November and December, and fishermen were reluctant to fish far from shore for uncertain catches of a fish for which there was no firm market. The gross similarity of these fish to the shallow water cisco or lake herring (*L. artedi*), the only other cisco in Lake Erie, hindered their clear recognition as anything truly different by the fishermen, or by biologists who may have examined catches of lake herring in which one or a few deep water forms may have been present. Difficulties of recognition under such circumstances would be even greater in Lake Erie than in other lakes because the lake herring, the most variable member of its genus (Koelz, 1929), has displayed a wider variation of forms in Lake Erie than in any other single body of water. So diverse are the forms of lake herring there that this single species has been at times described as at least six species (Dymond, 1922).

The bloater (*L. alpenae*) in Lake Erie was first recognized positively during a study of the Lake Erie cisco (lake herring) during 1945–49 sponsored by the Ontario Department of Lands and Forests and the Research Council of Ontario (Scott, 1951). Commercial catches at Port Dover in 1946 produced 6 specimens that seemed to stand conspicuously apart from the hundreds of other ciscoes examined because of their broader back and heavier head and head parts. Another such specimen was located among ciscoes landed at Erieau in 1947. Closer examination of these fish revealed gill-raker counts ranging from 30 to 34, decidedly below the counts of 37–55 for 1,300 shallow-water ciscoes taken during the same period (Scott, 1950). These fish most closely resembled *L. alpenae* and *L. johannae* of Lakes Michigan and Huron, but positive identification was difficult because so few specimens were available. A tentative identification as *L. johannae* (Scott, 1954) was, however, made because gill-raker counts of the few fish taken matched *L. johannae* better than *L. alpenae*.

A general fishery survey of Lake Erie by the United States Bureau of Commercial Fisheries in 1957 again turned up a conspicuously different cisco in the east end of the lake. Biologists of the research vessel *Cisco*, unaware of the specimens taken in 1946 and 1947, tentatively identified their first specimens as *L. alpenae* because of the close resemblance to the same species of Lake Huron where they had conducted a fishery survey in 1956. By the end of the year 38 specimens had been collected, 16 from one gill-net set on November 13, 1957. Further examination of the 38 specimens collected in 1946–47 and 1957 now permits their positive identification as *L. alpenae*.

MATERIALS AND METHODS

Six bloater ciscoes used in this study were taken in August and September 1962 from commercial gill nets fished near Port Dover, Ontario (ROM Nos. 13758, 13759, 13760, 13761, 13762). Another specimen was obtained from a commercial catch landed at Erieau, Ontario, in July 1947 (ROM No. 13755).

Twenty-six specimens were collected in May–November 1957 in the vicinity of Long Point in eastern Lake Erie (UMMZ Nos. 178,808–178,816, ROM No. 21,808). Of these, 24 were taken in experimental gill nets fished by the research vessel *Cisco* (United States Bureau of Commercial Fisheries) on the bottom at 33–34 fathoms (60–62 m). One specimen was caught in a trawl dragged on the bottom in 17 fathoms (31 m) and another was taken within 20 feet (6 m) of the bottom in a gill net fished from the surface to the bottom at 80 feet (24 m).

Morphometric measurements and counts generally follow those used by Koelz except that dorsal and anal ray counts include all rays regardless of length; this procedure increased counts by 1 or 2 (averages, 1.8 and 1.4, respectively) over those of Koelz (1929). Measurements and counts in addition to those made by Koelz include: the distance from the tip of the snout (junction of premaxillaries) to the insertions of the pectoral and ventral fins; the interorbital distance—least distance across the top of the head between bony margins of the orbits; length of lower gill arch—distance from lateral insertion of center gill raker to the anterior base of the anterior gill raker on lower arm of the first gill arch; length of center gill raker—distance from lateral insertion of the center gill raker to its tip; the number of scale rows around the body immediately anterior to the dorsal fin; and number of scale rows around the caudal peduncle immediately anterior to the dorsal insertion of the caudal fin.

All counts and measurements were made on the 26 specimens collected in 1957. Several counts and measurements were made of the 7 specimens collected in 1946–47 shortly after collection. As these fish were measured fresh and the 26 specimens collected in 1957 were measured after 2 years of preservation, discussions of measurements are based mainly on the later collections to avoid discrepancies that may have resulted from shrinkage following preservation. A summary of measurements and counts for the 26 fish collected in 1957 is given in Table I.

Comparisons are made with data presented by Koelz (1929), and with 25 *L. alpenae* and 26 *L. artedi* collected in Lake Huron in 1956. The 13 *L. artedi* collected along with *L. alpenae* in Lake Erie in 1957 are used to show distinguishing characteristics between the species. Proportions based on body measurements were used for only 11 *L. artedi* as 2 had badly deformed vertebral columns and distorted bodies.

The authors are indebted to Mr LaRue Wells who collected specimens used for this study during the cruises of the research vessel *Cisco* in 1957.

IDENTIFICATION

Koelz (1929) found *Leucichthys alpenae* to resemble *Leucichthys johannae* more closely than any other cisco of the Great Lakes. The most discriminating means of distinguishing between the two species were differences in numbers of gill rakers, lateral line scales and pectoral rays, and in the pectoral-ventral distance/pectoral length (PV/P) and ventral-anal distance/ventral length (VA/V) ratios. Koelz's comparisons between the two species in Lakes Michigan and Huron showed that *L. alpenae* tended to have a greater number of gill rakers.

TABLE I. Proportional measurements of *L. alpenae* collected in Lake Erie, expressed in thousands of standard length.

Measurement	Mean	Range
Body[1]		
Standard length (millimeters)	245	219–268
Snout to adipose origin	853	836–878
Snout to dorsal origin	506	487–526
Snout to anal origin	784	761–813
Snout to ventral insertion	549	517–579
Snout to pectoral insertion	228	211–242
Pectoral insertion to ventral insertion	330	297–358
Ventral insertion to anal origin	253	234–287
Body depth	241	218–276
Body width	142	121–201
Caudal peduncle depth	75	68– 83
Fins[1]		
Pectoral length	171	160–184
Ventral length	172	148–184
Anal height	119	108–134
Anal base length	107	94–148
Dorsal height	170	100–187
Dorsal base length	107	90–128
Adipose length	75	67– 84
Head[1]		
Head length	233	220–248
Head depth	150	144–162
Mandible length	115	101–123
Maxillary length	86	76– 99
Snout length	62	57– 67
Eye diameter	52	48– 57
Interorbital distance	64	54– 73
Lower gill-arch length	107	100–113
Center gill-raker length	36	31– 42
Counts[2]		
Gill rakers	36	30– 39
Lateral line scales	76	68– 83
Scale rows around body	41	38– 45
Scale rows around caudal peduncle	20	18– 21
Vertebrae	58	56– 59
Dorsal fin rays	12	10– 13
Anal fin rays	12	10– 14
Pectoral fin rays	15	13– 16
Pelvic fin rays	11	10– 13

[1]Measurements of 26 fish collected in 1957.
[2]Counts of 7 fish collected in 1946–47 and 26 fish collected in 1957 except for scale rows and pectoral rays which include only the latter.

fewer lateral line scales, fewer pectoral rays, and larger PV/P and VA/V ratios than *L. johannae* (Table II). Koelz's series of collections of ripe and spent *L. johannae* indicated a spawning period from late August into September, but he had only indirect evidence that *L. alpenae* spawned in November, a period later confirmed by Jobes (1949). Although the counts and measurements showing differences between the species may overlap, the different spawning periods demonstrate reproductive isolation.

Counts and ratios of the *L. alpenae* taken in Lake Erie in 1946–47 and 1957 agree very closely with the records of Koelz for this species in Lake Huron and Michigan, and show the same differences used by Koelz in distinguishing them

TABLE II. Counts and measurements that distinguish *L. johannae* and *L. alpenae* in lakes where they occur. Figures in parentheses are extremes of range, and central figures give 80–90% range. Data from Lakes Michigan and Huron are from Koelz (1929).

Species and lake	Gill rakers	Lateral line scales	Pectoral-ventral /ventral	Ventral-anal /ventral	Pectoral rays
Leucichthys johannae					
Lake Michigan	(26)27–32(36)	(74)80–90(95)	(1.5)1.6–1.8(2.1)	(1.1)1.2–1.5(1.6)	(14)16–17(20)
Lake Huron	(25)27–31(35)	(67)77–87(91)	(1.3)1.5–1.8(2.1)	(1.0)1.2–1.4(1.6)	(15)17–18(19)
Leucichthys alpenae					
Lake Michigan	(33)36–43(46)	(71)78–85(96)	(1.6)1.9–2.2(2.5)	(1.2)1.4–1.7(1.9)	(12)15–17(18)
Lake Huron	(31)34–40(44)	(70)76–83(91)	(1.6)1.8–2.1(2.3)	(1.3)1.4–1.7(1.9)	(14)15-17(18)
Lake Erie	(30)31–38(39)	(68)72–81(83)	(1.7)1.8–2.1(2.2)	(1.3)1.4–1.7(1.8)	(13)14–16

from *L. johannae* (Table II). Although gill-raker counts of *L. alpenae* in Lake Erie are lower than in Lakes Huron and Michigan, approaching the counts of *L. johannae*, the number of lateral line scales and pectoral rays for *L. alpenae* in Lake Erie are more divergent from *L. johannae* than in the other lakes. The PV/P and VA/V ratios of *L. alpenae* show the same degree of difference from *L. johannae* in all three lakes. All of the *L. alpenae* taken in Lake Erie on November 11, 1957, were ripe and had well developed pearl organs. The indication of a late-November spawning period is in agreement with the spawning period of this species in other lakes and differs from the August–September spawning of *L. johannae*.

The possibility of confusing *L. alpenae* with *L. johannae* has been much reduced if not eliminated in recent years. In 1954–55 no *L. johannae* were found in a study of the chubs of Lake Michigan (Moffett, 1957) and none were found during a similar study of southern Lake Huron in 1956. These observations may indicate that the species has become either extremely rare or extinct. Its moderately large size and deepwater habitat would have made it particularly vulnerable to depredation by the sea lamprey during and particularly following destruction of the lake trout in these lakes (Hile, 1949; Hile *et al.*, 1951; Eschmeyer, 1957).

Clemens (1922) described 5 separate species of ciscoes in Lake Erie. Koelz (1929) later included 4 of these species in a list of synonyms for *L. artedi*, and believed that the fifth, *L. prognathus*, was actually *L. artedi albus* based upon his own examination of ciscoes from the eastern end of Lake Erie. Koelz (1924) considered *L. prognathus* conspecific with *L. alpenae*, but also gives it in synonym lists for *L. hoyi* and *L. nigripinnis* (Koelz, 1929). The present record of *L. alpenae* in Lake Erie again raises the question of the status of *L. prognathus* reported by Clemens which he called the longjaw cisco. Clemens reported that his longjaw cisco was taken in eastern Lake Erie between Port Dover and Port Maitland which is within the area inhabited by *L. alpenae* of the present report. Clemens also described his longjaw cisco as having a ". . . long mandible which usually extends beyond the upper jaw . . . relatively long bony snout . . . narrow caudal peduncle . . . ", which are all characteristic of our *L. alpenae*. The

gill-raker counts, however, ranged from 41 to 46 and fall well outside the range of *L. alpenae* and within the range of the Lake Erie lake herring. Thus the longjaw described by Clemens could not have been the same as the longjaw reported here, and must have been no more than a selected group with similar features from the highly variable population of *L. artedi*, as were the other 4 species described by Clemens.

The only other record from Lake Erie that may have a bearing on our record is based on a single specimen taken from fish landed at Erie, Pennsylvania, in December 1914 that were caught in the deep hole north of Erie. This specimen (U.S. National Museum No. 76,845) was described by Bean (1916) as a new species, *L. macropterus*. This specimen was characterized by very long pectoral, pelvic, dorsal and anal fins which were 39, 44, 35, and 29 percent of the body length respectively. This fish has been considered an anomalous specimen by subsequent authors (Dymond, 1922; Koelz, 1929) and ignored since no specimens like it have subsequently been taken. The body proportions given by Bean agree reasonably well with those of our *L. alpenae*, and the gill-raker count of 30 gives good reason to believe that this specimen may have been an aberrant *L. alpenae* rather than *L. artedi* as believed by other authors.

DISTINGUISHING CHARACTERS

The longjaw cisco is one of 3 coregonid species inhabiting Lake Erie. The other 2 are the lake herring and the lake whitefish (*Coregonus clupeaformis*). The whitefish is very clearly distinguishable from the ciscoes of the Great Lakes by its retrorse premaxillaries, subterminal mouth, and low gill-raker number.

In gross appearance the longjaw cisco stands apart from the lake herring because of its heavier and larger head and head parts, a blunter nose (as viewed from above), and generally lighter pigmentation, particularly of the mouth parts. The tip of the lower jaw also tends to extend beyond the premaxillaries in nearly 50% of the specimens whereas the jaws of lake herring are usually equal. The common name "longjaw cisco" was given to populations from Lakes Michigan and Huron where the lower jaw extends beyond the upper in nearly every specimen.

Although the dimensions of the head and head parts are useful in distinguishing between the longjaw cisco and lake herring, proportional measurements of these do not provide as satisfactory a separation of these species in Lake Erie as in Lake Huron. The relative length and depth of the head is clearly greater for *L. alpenae* in both Lakes Huron and Erie but the distributions of ratios overlap much more broadly in Lake Erie than in Lake Huron (Table III). A similar comparison of mouth size is demonstrated by the frequency distributions of maxillary and mandible lengths (Table IV). Other head parts show similar relations. Measurements of head size and mouth size provide an almost complete separation of the species in Lake Huron, but are of limited value in Lake Erie where identification must be based largely on gross appearance. Thus in field identification of fish from Lake Erie, those fish for which several or all of the head

TABLE III. Frequency distribution of head length and head depth divided by standard length of *L. alpenae* (*alp*) and *L. artedi* (*art*) in Lakes Erie and Huron.

Head length/standard length					Head depth/standard length				
Thousandths of standard length	Lake Erie		Lake Huron		Thousandths of standard length	Lake Erie		Lake Huron	
	alp	*art*	*alp*	*art*		*alp*	*art*	*alp*	*art*
205–209	...	...	...	1	120–124	...	...	...	1
210–214	...	2	...	3	125–129	...	...	...	8
215–219	...	2	...	6	130–134	...	1	...	7
220–224	2	1	...	7	135–139	...	1	3	8
225–229	6	2	1	2	140–144	3	2	2	1
230–234	6	2	3	2	145–149	9	3	6	1
235–239	8	2	3	3	150–154	11	4	4	...
240–244	3	...	1	2	155–159	2	...	5	...
245–249	1	...	5	...	160–164	1	...	3	...
250–254	...	...	2	...	165–169	...	...	1	...
255–259	...	...	5	...	170–174	...	...	1	...
260–264	...	...	3	...					
265–269	...	...	2	...					
Number of fish	26	11	25	26		26	11	25	26
Average	233	227	249	224		150	146	151	132

TABLE IV. Frequency distribution of the maxillary and mandible lengths divided by the standard length of *L. alpenae* (*alp*) and *L. artedi* (*art*) in Lakes Erie and Huron.

Maxillary length/standard length					Mandible length/standard length				
Thousandths of standard length	Lake Erie		Lake Huron		Thousandths of standard length	Lake Erie		Lake Huron	
	alp	*art*	*alp*	*art*		*alp*	*art*	*alp*	*art*
55– 59	...	...	...	1	90– 94	...	...	...	3
65– 69	...	...	...	2	95– 99	...	2	...	4
70– 74	...	1	...	6	100–104	1	1	...	7
75– 79	2	4	...	11	105–109	5	3	...	7
80– 84	7	5	...	2	110–114	5	3	1	3
85– 89	11	1	2	1	115–119	9	2	4	2
90– 94	4	...	6	3	120–124	6	...	5	...
95– 99	2	...	7	...	125–129	...	...	7	...
100–104	...	...	8	...	130–134	...	...	3	...
105–109	...	...	1	...	135–139	...	...	4	...
110–114	...	...	1	...	140–144	...	...	1	...
Number of fish	26	11	25	26		26	11	25	26
Average	86	79	98	77		115	108	127	104

features tend to be heavier would be classed as *L. alpenae*. Of course other features such as degree of pigmentation, bluntness of snout, and protruding lower jaw are considered.

With experience, fish can be identified by these characters with a high degree of accuracy, but head features are not good taxonomic characters as they can be modified by the environment (Hile, 1937; Svärdson, 1950, 1951). Indeed, environmental influences may be largely responsible for greater similarity between the longjaw cisco and lake herring in Lake Erie than in Lake Huron. Both species are found together below the thermocline in the restricted area of the

deeper (maximum depth 35 fathoms or 64 m) eastern basin of Lake Erie during most of the year. Recent evidence of summer oxygen depletion (Carr, in press) and temperature increase Beeton (1961) in other areas of the lake suggest even greater confinement to the limited cold-water segment of the lake. In Lake Huron, however, lake herring are distributed throughout shallower areas of the open lake while the longjaw cisco inhabits the extensive deeper areas. Thus if environment did influence head proportions, one would expect greater similarity in Lake Erie than Lake Huron, almost to the limit of the genotypic plasticity of the two species.

More positive distinction can be made between the longjaw cisco and lake herring of Lake Erie by gill-raker counts (Table V). This character has been demonstrated in transplantation experiments of coregonids to be little influenced by the environment. In fact, gill-raker counts of the two species are better separated in Lake Erie where the species live in a more restricted environment than in Lake Huron where they occupy different habitats (Table V). This situation is the reverse of the relationship of head features. Although collections of *L. alpenae* taken in 1946–47 and 1957 showed no overlap in gill-raker counts with *L. artedi* collected in 1957 or the range of 41–53 reported by Koelz (1929) for Lake Erie, counts of over 1300 *L. artedi* collected in 1946–47 ranged from 3[illegible] to 53 (Scott 1950), indicating some overlap.

TABLE V. Frequency distribution of gill-raker counts of *L. alpenae* and *L. artedi* in Lakes Erie and Huron.

Number of gill rakers	Lake Erie		Lake Huron[3]	
	alpenae[1]	*artedi*[2]	*alpenae*	*artedi*
30	2	...	...	...
31	1	...	...	...
32	1	...	...	...
33	4	...	1	...
34	5	...	1	...
35	7	...	3	...
36	5	...	5	...
37	5	...	4	...
38	2	...	5	...
39	1	...	3	...
40	...	...	1	...
41	...	...	1	2
42	...	2	1	...
43	...	1	...	2
44	...	1	...	2
45	...	2	...	2
46	...	3	...	7
47	...	1	...	2
48	...	...	...	6
49	...	1	...	1
50	...	2	...	1
51	...	...	...	1
Number of fish	33	13	25	26
Average	34.8	45.8	37.2	46.2

[1]1946–47 and 1957 collections.
[2]1957 collections.
[3]1956 collections.

A simple discrimination index based on gill-raker number, gill-raker length, and length of the lower arm of the gill arch has been used successfully to distinguish among several species of European coregonids (Dottrens, 1959). The lengths of the lower gill arch and the center gill raker are of considerable value in separating *L. artedi* and *L. alpenae* of Lake Erie although some overlap occurs (Table VI). The formula below yields a broad separation of *L. alpenae* and *L. artedi* in Lake Erie:

$$F = R + \left(\frac{100\ CR}{LA}\right)$$

Where: F = a discriminant function
R = number of gill rakers
CR = length of center gill raker
LA = length of lower gill arch

Values of F for individual *L. alpenae* ranged from 64 to 77 (mean 69.2) and for *L. artedi* from 82 to 96 (mean 89.5). These values, in a sense, provide a numerical expression of the discrimination used in distinguishing between species by gross examination where the relationships among several characteristics are considered simultaneously.

TABLE VI. Frequency distribution of the lower gill-arch and center gill-raker lengths divided by standard length of *L. alpenae* (*alp*) and *L. artedi* (*art*) of Lake Erie.

Length of lower gill arch/standard length			Length of center gill raker/standard length		
Thousandths of standard length	*alp*	*art*	Thousandths of standard length	*alp*	*art*
84– 85	...	1	31	1	...
86– 87	...	2	32	1	...
88– 89	...	1	33	4	...
92– 93	...	1	34	2	...
94– 95	...	1	35	1	1
96– 97	...	2	36	7	1
98– 99	...	1	37	5	...
100–101	2	1	38	2	...
102–103	5	...	39	...	...
104–105	4	1	40	2	3
106–107	3	...	41	...	2
108–109	5	...	42	1	1
110–111	5	...	43	...	3
112–113	2	...	...	...	...
Number of fish	26	11		26	11
Average	107	94		36	40

AGE, GROWTH AND MATURITY

The 6 longjaw ciscoes collected in 1946 belonged to age-group III (3 completed annuli), and the single specimen of 1947 to age-group IV, thus all were members of the 1943 year-class. Of the fish collected in 1957 all but one belonged to age-group III and the remaining specimen, the first collected that year (in

May) belonged to age-group IV. Sampling in 1956 was by graded gill nets c 1- to 4-inch mesh with longjaw ciscoes taken in $1\frac{1}{2}$- to 3-inch mesh. Hence either few fish live beyond age III, or else the two sampling periods by chanc coincided with periods when two dominant year-classes had reached age III.

Total length of the 6 longjaw ciscoes taken in 1946 at age III ranged fro 12.2 to 13.6 inches and averaged 12.8 inches (310–345 mm, av. 325) and th age-group IV fish taken in 1947 was 13.7 inches (348 mm).[3] The 25 age-grou III fish taken in 1957 ranged from 10.2 to 12.6 inches and averaged 11.6 inche (259–320 mm, av. 295 mm) and the single age IV fish was 11.7 inches (297 mm long. The decrease of 1.2 inches (30 mm) for III-group fish between the 194 and 1957 collections reflects poorer growth and may, in part, have been influence by recent indications of progressive eutrophication of Lake Erie (Beeton, 1961

The growth rate as determined by back calculation from scale measurement of longjaw ciscoes collected in 1957 follows the classical growth pattern (Tabl VII). This growth rate compares favorably with calculated total length of 5.6, 8.3 and 10.3 inches (142, 211, 262 mm) at the ends of years 1, 2 and respectively, reported by Jobes (1949) for the longjaw of age-group III, fro Lake Michigan. Both the growth pattern and growth rate are, however, i sharp contrast with that of the lake herring taken in the same nets with the lon jaw ciscoes in Lake Erie (Table VII). The lake herring averaged only 2.

TABLE VII. Comparison of the growth of *L. alpenae* and *L. artedi* of age-group III collected the same nets in Lake Erie in 1957. Lengths shown are total lengths calculated from sca measurements.

Species	No. of fish	Length at end of year of life			Length at end of year of life		
		1	2	3	1	2	3
		inches	*inches*	*inches*	*mm*	*mm*	*mm*
L. alpenae	25	5.1	8.6	10.6	130	218	269
L. artedi	10	2.7	7.6	10.3	69	193	262

inches in their first year—nearly half the 5.1 inches of the longjaw cisco.[4] Muc more rapid growth of the lake herring during the next two years narrowed th gap between the species to 0.3 inches. It is most unusual, however, to fin a fish that hatches in the early spring to grow less in its first year than in i second—certainly a phenomenon not known in any other coregonid populatio The resultant scale pattern in *L. artedi* was so strinkingly different from *L. alpenae* it served as an additional distinguishing characteristic separating th longjaw ciscoes and lake herring collected in 1957.

All specimens of longjaw ciscoes taken in Lake Erie in 1957 were matu indicating that maturity must be reached at least by the start of the fourt

[3]Total lengths (to the longer tip of the tail when adjusted to the position of maximu extension) were calculated by multiplying standard length, measured when fish were fresh, b 1.1986; this factor was obtained from measurements of specimens collected in 1957.

[4]Cursory examination of lake herring scales collected in the 1940's showed a normal grow pattern with rapid growth in the first year.

rowing season. Specimens taken on November 13 all had very well developed onads, and one male appeared to be at least partly spent. The lake herring aken early in November also had well developed gonads, but appeared to be little farther from spawning. Pearl organs of the lake herring were also not s well developed as those of longjaw ciscoes taken at the same time.

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What Oceanography Means to Fishermen

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Abstract

Oceanography has provided knowledge of average conditions in the ocean and the processes maintaining them in equilibria. Augmentation of oceanographic effort now under way may be directed in large part toward attaining prediction capability especially of departures from average conditions in the upper mixed layer and the thermocline. This may be accompanied by parallel research effort on the ecological requirements and behavior of food fish and shellfish to provide understanding of their responses to environmental change. Combined, these efforts will have practical meaning to fishermen if it enables them to eliminate time lost in scouting for fish and in fishing on less than optimal concentrations, and so lower their cost of fishing and keep their product competitive with agricultural products and imported fish.

FROM A DISTANCE OF SEVERAL THOUSAND MILES I have noted with admiration he growth of interest in, and advancement of, the studies of the ocean and s fishery resources in the Gulf and Caribbean and adjacent Atlantic that have ccurred during the last several decades—stimulated, I am sure, by the an-ual meetings held by this Institute. I am grateful to have this opportunity of articipating in this one.

Knowing that expansion of oceanographic effort has recently assumed a nore important place in the national policy of this country and that one of he reasons, among many others, given for this is "to get more food from the ea," one may well ask "what does this mean to the fisherman?" Well known o all in this room, and felt most keenly by the fishermen among us, is the lifficulty the fisherman is having in selling the food he garners from the sea at price that will keep him in business.

This is getting more difficult every day. Advances in agricultural research nd the wider use of machinery have combined to make farming vastly more roductive per acre and per man than heretofore. Technological advances in rocessing farm products have made them more attractive to the housewife. The competition in the market from farm products becomes ever more pressing n fishery products. Added to this is the increasing competition from imported ishery products, an inevitable consequence of our national policy of encouraging international exchange of goods.

Under these circumstances, what does oceanography mean to the fisherman? Obviously it cannot give his product a preferred place in the market. If it is to nean anything to him, beyond giving some intellectual satisfaction from know-

ing more about the sea on which he sails and from which he extracts a livir it must enable him to catch his fish at less cost, and with no degradation quality.

Can oceanography help him do this?

To examine this question, we must first inquire what oceanography is, present state and its future prospects.

Broadly speaking, oceanography is the study of the ocean, its boundaries, contents and the dynamic processes going on within it. This is a very bro field of study and inherently difficult because most of the ocean is inaccessil except by instrumented probes. The number of dollars, ships, and men devot to this study in the past have been far too few, in proportion to the size the ocean and the inherent difficulties of studying the problems it presen Progress has been painfully slow, and for this reason oceanography, we mu admit, has not held much practical meaning to the fisherman.

A generation ago the major motivation and major support for oceanograp came from fisheries. This is now undergoing rapid change. With the adve of the submarine as a decisive strategic weapon in World War II, our Na has become aware that an intimate knowledge of subsurface conditions a events is vital to the successful tactical employment of this weapon and succe ful tactical defense against it. There, too, is an increasing awareness th improvement in short- and long-range weather forecasts depends on a full understanding of energy exchanges between ocean and atmosphere. Dispo of wastes, both ordinary and radioactive, increasingly involves the use of t ocean.

All of these combine to augment the motivation and the support for stu of the ocean. Progress will accelerate, and understanding sufficient to predi ocean conditions will be achieved, many times sooner than could be expect even a short time ago.

What does this mean to the fisherman?

Some say that fishermen are using century-old hunting methods; that ocean graphic knowledge will enable the fisherman to employ entirely new princip to concentrate the fish and scoop them up almost automatically. Some say th we ought to forget the fish at higher trophic levels and concentrate on tho at lower trophic levels; or even go farther down the food chain and harve the plankton of the sea, there is so much more of it. Some say that oceanogr phic knowledge will enable us to control the ocean, or some parts of it, fertili it, plant the right kinds of food fish (or shellfish), weed out the trash fish, a produce much more fish (or shellfish) with much more regularity and of mu higher quality, just as farmers are doing with land plants and animals.

I do not disagree with these ideas and assertions. But I do not think that the promises will be fulfilled by sudden, magic breakthrough in the near future, during the life-time of anyone in this room. Rather, I suggest that fisherm are already taking advantage of advanced technologies as fast as they becon practical. They are using the echo-sounder to locate the bottom and conce trations of bottom fish, and some have, to their sorrow, tried to use sonar locate fish schools even before it was fully practical. They have adopted nyl cordage for lines and nets and are continuously employing more machi power to replace man power.

I suggest that for a long time to come, it will be more efficient to let the ood fish concentrate the organisms of the lower trophic levels, convert them nto flesh and then catch the food fish when they concentrate, as most fish do t some times and some places.

I suggest that fish farming in the open ocean will require the control of such irge forces and involve the use of such large sources of energy, that it lies in ie very far distant future. But fish and shellfish farming in partly enclosed stuarine situations is already practiced and can be greatly extended if we shery people get around to it before other activities of mankind pre-empt the stuaries for other uses—as for instance, waste disposal.

In other words, I suggest that the effect of progress in oceanography on sheries will be a slow evolutionary process, and wish to explore today, some dvances that appear feasible in the near future. These have to do with the ost of catching fish, by present conventional, or only moderately improved, nethods.

Most of these costs are inescapable and many are rising. But one of the arge factors in the cost to the fisherman, per pound, of landing a load of fish t the dock is how long it takes him to find a concentration of fish and how nuch he can catch out of the concentration after he has found it.

Obviously it would mean much to the fisherman if oceanography could upply information that he could use to find fish more quickly, in concentra- ions yielding good catches and do this reliably, thereby substantially lowering his cost of fishing.

Frankly, I do not know whether oceanography can do this; or, if it can, iow soon.

Oceanography has already given us an understanding of the average marine nvironment. We know that the ocean is essentially made of two layers; a hin restless upper layer perhaps a hundred fathoms deep overlaying the con- inental shelves, and farther offshore, floating on top of a very thick sluggish ayer extending to the sea bottom. The upper layer is ever changing; warmed by the sun, mixed by the winds, and containing the well-known fast-flowing ocean currents, and it is the zone where one-celled plants utilize the energy of unlight to produce living material that sustains all animal life in the sea from he tiny copepods to the great whales.

The lower layer is eternally cold, shrouded in perpetual darkness and iardly changing with seasons or centuries. By the decomposition of waste natter raining down from the productive layer above, it becomes the reservoir of oceanic fertility.

Separating the two layers is a zone of rapid decrease in temperature, the hermocline, which varies in depth both in time and space. It may form a barrier to descent by most epipelagic fishes. It prevents recharging of the upper nixed layer with nutrient salts from the reservoir below except when and where t is disrupted by upwelling, convective mixing from winter cooling, and tur- bulence of current boundaries. Consequently, over much of the deep ocean, life is sparse, but at the locations of thermocline disruption it can be very rich.

Moving horizontally across the ocean we encounter water masses with dif- ferent physical and chemical characteristics, containing different biological regimes, and whose boundaries sway with season and vary irregularly from year to year.

These vertical and horizontal features determine the abundance and distrib tion of the life in the sea. Through evolutionary time, each kind that h survived until now has become adapted to some particular combination conditions; and it has developed patterns of behavior, of migration, of feedi and of spawning that enable it to respond successfully to the changes in t undersea climate and to follow the conditions suited to it when they becon displaced by undersea climatic irregularities.

To find good concentrations of fish in a catchable state of behavior, and do this regularly, oceanographers and fishermen must know what conditions look for and where to look. They must know not only the average conditio but the variations from them and be able to predict these variations.

There is not time to enumerate the different attacks on these problems bei made by many research groups.

Instead, I will attempt to convey some indication of the nature of the pro lem, its difficulties and some notion of the state of progress in one approa being followed at our Bureau of Commercial Fisheries Biological Laborato at Stanford. Our motivation, of course, is fishery oriented and our approach to find out by examining the historical record what changes have taken place the North Pacific ocean climate in the past and how these have affected t fisheries.

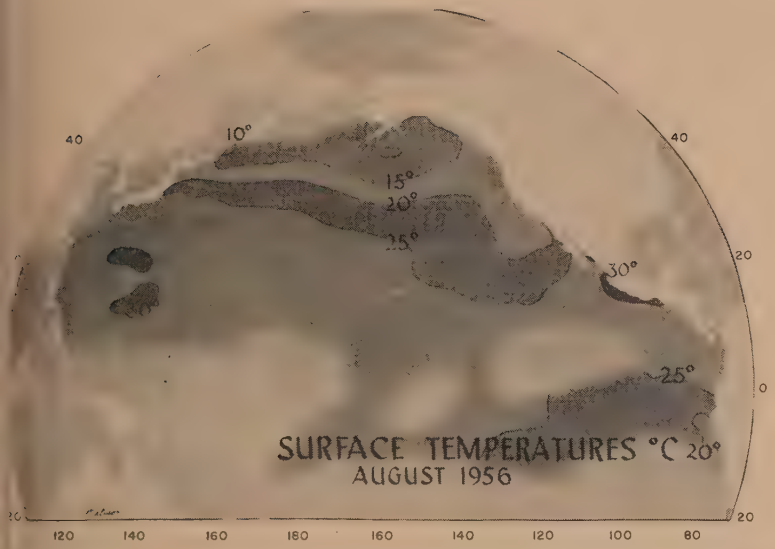
In the eastern Pacific we have experienced one marine climatic regime relatively cool conditions over ten years duration followed by another of rel tively warm conditions of about three years duration. As we might have e pected, if we had anticipated it, there were concurrent displacements in t centers and boundaries of fish distribution.

The change from the ten-year regime to the three-year regime took pla between 1956 and 1957. The transition occupied a number of months but August of 1957 had reached a stage where its nature became quite evide in the ocean-wide field of sea-surface temperatures. The field for August 19 is shown in figure 1.

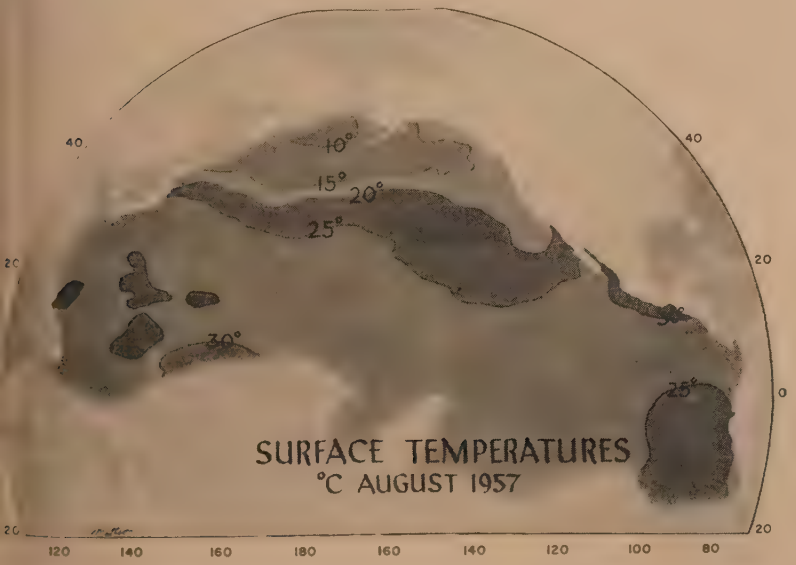
I should say at this point, that the reduction of a vast number of temper tures to chart-form is owing to the efforts of my associates, J. F. T. Sa Oceanographer, and L. E. Eber, Meteorologist, who have now produced su charts for each of the 24 months of 1956 and 1957 which are to be publish as the first installment of an Atlas of Pacific Sea Surface Temperatures for long a series of years as the historical data are of sufficient abundance a reliability to describe the temperature field.

As we would expect, the temperature field reflects basically the polewa decline of temperatures upon which is superimposed the effects of the curre system in transporting water and its heat content. On the west we find war water extending northward as the result of transport by the Kuroshio, and co water extending southward as the result of transport by the Oyashio, packi the isotherms closely just north of the elbow of the Japanese island of Honsh

Eastward we find the isotherms spreading apart as the north Pacific w wind drift approaches the American coast and branches north and sou conveying warmer water northward into the colder water of the Gulf Alaska Gyre and colder water southward as the California Current along t Washington, Oregon and California coasts into the area that otherwise wou be warmer.



IGURE 1. The field of sea surface temperatures over the North and Tropical Pacific in August 1956, in °C.



IGURE 2. The field of sea surface temperatures over the North and Tropical Pacific in August 1957, in °C.

The same general picture is portrayed in the temperature field for Aug 1957 (Fig. 2). But note that there is a closer packing of isotherms off Japan wider spreading off the American coast. Also the 15° and 20° isotherms dulate in opposite directions in the two years.

The differences are more easily seen when we subtract the 1956 temperat field from that of 1957, giving us the difference between the two Aug (Fig. 3).

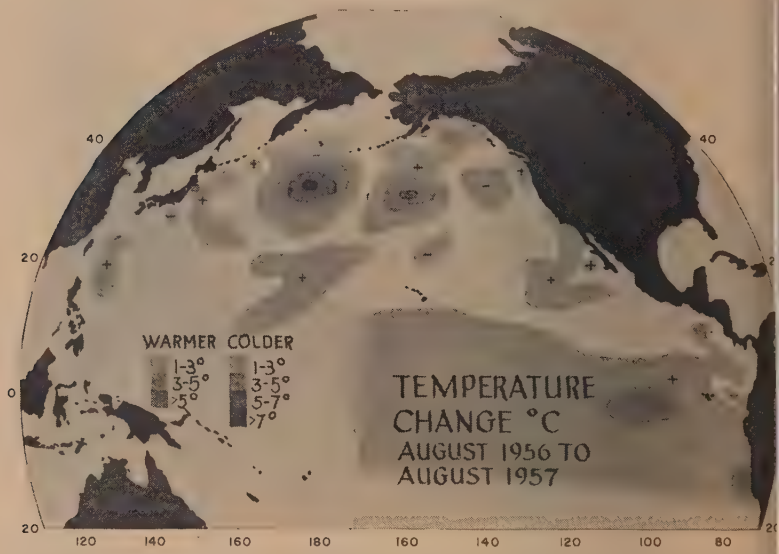


FIGURE 3. The change in sea surface temperatures over the North and Tropi Pacific from August 1956 to August 1957, in °C. Areas warmer in 1957 th in 1956 are marked with a plus sign; those colder in 1957 than 1956 a marked with a minus sign.

We see in 1957 in the temperate latitudes that a large area was much col in west and another large area much warmer in the east. Most of the rest the Pacific was warmer in 1957, but more moderately so, except off Pe where temperatures over a vast area reached heights approaching warm Nino conditions.

These temperature differences in the transition zone between the subarc water mass and the subtropical central Pacific water span a wide range, fr over 7°C colder in the west to more than 5°C warmer in the east, a total 12°C or 21°F. Also large areas are affected, measured in the millions square nautical miles.

As warm-blooded land animals we cannot intuitively appreciate what t might mean to the cold-blooded animals of the sea.

Experiments have shown that fish can sense temperature changes as small as)5°C and respond to such slight changes. It is also well established that the :tabolic activity of cold-blooded animals slows down with a lowering of vironmental temperature and speeds up with a rise in environmental tem- rature. This profoundly affects the physiology of the animal and its activity. Thus, no matter whether the fish and other sea organisms shifted when there :re such large temperature changes, or whether they remained in the same :as and underwent the physiological effects of the different temperature gimes, there would still be major effects on the fishery.

We know that in 1957 a number of fishes responded to the more moderate rming along the American coast. For instance, the sockeye salmon forsook eir usual approach through the Straits of Juan de Fuca to the Fraser River d approached around the northern end of Vancouver Island and through hnston Strait. In 1958, when the difference became more extreme than in)57, sardines were taken in Monterey Bay by the tonnages unknown since)51. Barracuda and yellowtail, whose centers of abundance are off Lower alifornia, became exceedingly abundant in southern California waters. The opical tunas, skipjack and yellowfin tuna spread northward into southern alifornia waters and southward to the bulge of Peru, leaving a relative scarcity the middle of their range.

We know of these temperature changes and fish responses now; we were nly dimly aware of them at the time, and certainly could not have predicted em.

Prediction capability requires a knowledge of the processes that cause such nanges. We have begun to study this question and expect to pursue such udies more intensively.

From the mean atmospheric pressure fields that L. E. Eber is studying, it is)parent that the atmospheric circulation in January and August 1957 was arkedly different from the corresponding months of 1956. These differences ere of the kind and approximate magnitude to have produced the observed .fferences in sea surface temperature in the temperate latitude area either v wind-driven movement of the surface water, or by divergence-convergence rocesses, or a combination of both. The less pronounced changes in the other arts of the Pacific have not yet been studied.

If such changes are produced by altered atmospheric circulation and persist they did in 1957, or even if they do not persist, but lead time is offered by :liable extended weather forecasts, it appears quite within the near future state f our understanding to predict these shifts in oceanographic conditions and erhaps some of the consequences to some of the fisheries.

However, this appraisal may well be over-optimistic. There is a grave lack f information on the variable thickness of the upper mixed layer. The estimates f atmospheric effects mentioned above involved assumptions rather than data n the subsurface temperature structure. Such data probably can be secured ith sufficient continuity in time and space only by establishing a network of eep-anchored unmanned buoys with automatically operated instruments reach- ig down through the mixed layer and with telecommunication capability.

With defense and weather forecasting needs for gathering nearly the same ind of information as are wanted for fishery purposes, it seems that such a stem may eventuate in the near future in at least some parts of both oceans. iven such information-gathering facility, plus a reasonable amount of time

and adequate research effort, it is not outside the bounds of possibility that least the most marked changes of large extent and moderate duration can predicted.

The problems of monitoring and predicting more transient changes of sma scale are somewhat different. Oceanographic research is under way on th problems at a number of laboratories. The sensing instruments and the p ciples for translating the data into practical operating information will st from this research.

It is intended, by the example and by this discussion, to convey the kind information gathering and research required to predict environmental chan Their use in predicting the time and place of fish requires parallel informat gathering at sea and in the laboratory on the behavior of fishes and the for they feed upon. Time does not permit elaborating on this equally large a difficult area of endeavor. A beginning has already been made at several search centers and it is anticipated that such work will be given the expand support it requires in order to be fruitful.

The two branches of effort, the physical and the biological, are progress toward the goal of lessening the cost of catching fish. With this brief curso review of the state of this effort, it will be left to each of you to make own estimate of what oceanography means to the fisherman or what it m mean in the future, and when.

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RAFT CULTURE OF EASTERN OYSTERS IN CHATHAM, MASSACHUSETTS

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ABSTRACT

Growth and survival of raft grown oysters was studied in Oyster Pond and Oyster Pond River, Chatham, Massachusetts from 1957 through 1959. Seed oysters were supported off the bottom by a log raft for one year and then planted on the bottom for an additional year. Twenty-seven months after setting, most experimental oysters had grown to marketable size. They averaged 88.5 mm in height, 56.5 mm in length, and 4.6 mm in shell thickness. Approximately 17.4 per cent of the oysters died while attached to the raft and an additional 26.4 per cent died while on the bottom, it was estimated.

Under conventional methods of cultivation the Cape Cod oysters reach marketable size in four to five years, with mortality reported to be as high as 90 per cent in the first two years.

The development of raft culture on a self-sustaining basis is a possible solution for saving the declining oyster industry of Massachusetts and for rational utilization of potential oyster resources of the State.

INTRODUCTION

The production of oysters in Massachusetts (Fig. 1) has dropped over 80 per cent in the last 40 years. In the decade 1910-1919 the crop averaged 1222.5 thousand pounds of meats per year as compared to only 204.7 thousand pounds in 1950-1959 (Power, 1956-58 and New England Fisheries, 1959).

The reason for this decline is clear. At present the majority of oyster growers in Massachusetts are dependent on out-of-state bedding stock. Large oysters are bought from Long Island Sound in the spring, planted on small private grants, and sold in the fall and winter. Only oysters under the three-inch minimum legal size are left on the beds for more than one season.

1 Present address: U. S. Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries Biological Laboratory, Oxford, Maryland.

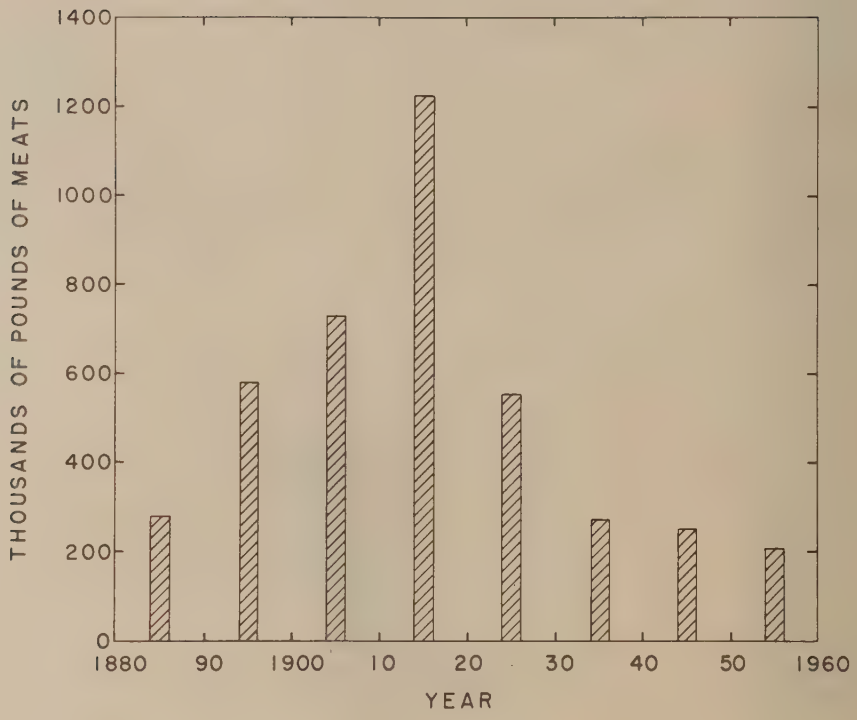

Fig. 1. Ten year annual average of oyster meats marketed in Massachusetts from 1880 to 1959.

Setting failure plus losses from predation and hurricanes have caused a shortage of oysters in Long Island Sound in recent years. Consequently, this area has not been able to supply all the Bay State growers with oysters and many oystermen have gone out of business.

In spite of the fact that the waters of Cape Cod are capable of producing thousands of bushels of seed oysters (Galtsoff, Prytherch and McMillin, 1930), the full development of this resource has never been realized because of the methods used. Since few seed oysters are grown in local waters there is a lack of oysters suitable for the half-shell market.

For 40 years the Japanese have successfully grown seed oysters to market size by suspending them from bamboo rafts. In one area of the Inland Sea 20,000,000 pounds of oyster meats are harvested annually by this method (Wallace, 1959).

With the hope of developing a similar culture which could be self-sustaining in Massachusetts, the Bureau of Commercial Fisheries at Woods Hole initiated studies on the growth and survival of oysters suspended from rafts in the fall of 1956. This report considers one phase of this study during the period from 1957 through 1959; a more detailed report will appear in a later publication.

METHODS

The raft was constructed of two 25-foot cedar logs held together by wooden cross bars (Fig. 2). A row of 46 staples, spaced three inches apart, was placed along each side of the log. The raft was moored in Oyster Pond River from August to November 1957, and from April through November 1958. During the winter of 1957, it was moved and anchored in Oyster Pond to protect it from being damaged and carried away by floating ice which can occur in the river during this period.

The experimental oysters came from a 1957 set caught in Mills Creek, West Chatham, Massachusetts. Oyster and scallop shells placed in chicken wire bags were used for cultch. Setting occurred around July 15. On August 22, 1957, a sample of this set was transferred to Oyster Pond River. Shells each bearing five or more young oysters were strung on No. 14 galvanized wire. There were approximately 20 pairs of shells on a wire, the pairs separated by a three-inch piece of plastic tubing. By August 30 all the strings were attached to the staples on the logs. During this period an oyster grower planted on the bottom near the raft about 20 bushels of oysters similar in age and origin to those suspended.

On November 13, 1958, the raft-grown oysters were planted on a private grant in the river. They remained on the bottom until November 30, 1959, when the majority of them were sold.

Growth was measured as increase in shell size. Once a month during the growing period the height (greatest dorsoventral distance) and length (greatest anteroposterior distance) of approximately 100 raft oysters were measured. Oysters do not grow from November to April in this area so no measurements were taken during this period. Survival among the suspended oysters was estimated by counting all live oysters on one string. By selecting the same string (Fig. 3) each month any decrease in the total number of live oysters from that counted the previous month could be considered natural mortality.

Fig. 2. Experimental log raft.

Fig. 3. String of raft oysters.

After the raft oysters were planted on the bottom they were left undisturbed for one year. A sample was then collected and the increase in shell size and the percentage of deaths (number dead divided by the total sample) recorded.

RESULTS

The results of our experiments demonstrate that the rate of shell growth is greatly accelerated when oysters are supported off the bottom. This observation is in agreement with the findings of Bonnot (1935) and Quayle (1956). By the end of 1957, the setting year, the raft oysters grew to a mean height and length of 28.5 and 23.6 mm respectively (Table 1, Fig. 4). The rate of shell growth of oysters on the bottom was

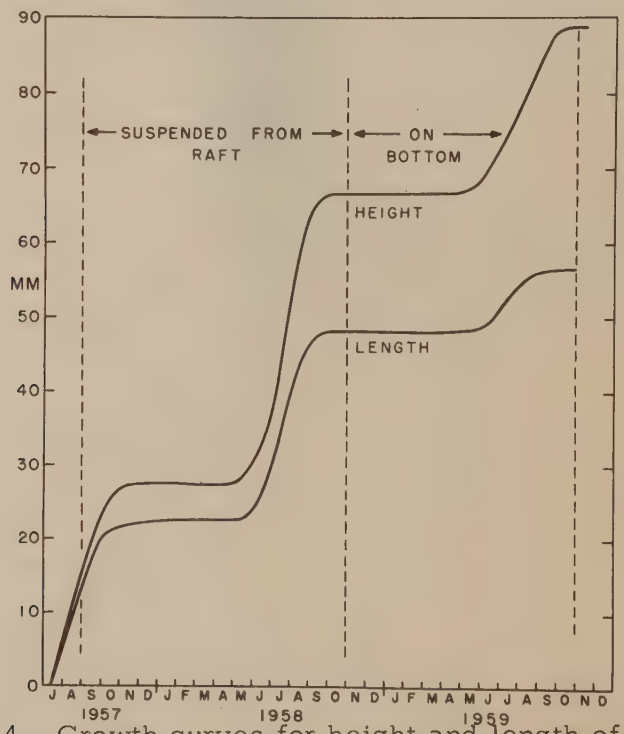

Fig. 4. Growth curves for height and length of raft oysters, 1957-1959.

slower; the average height was 20.0 mm and the average length was 16.0 mm. Unfortunately the young oysters on the bottom were lost during a winter storm and further comparison could not be made.

Table 1. Mean height and length, standard deviation, and standard error of the mean for raft grown oysters

Date sam-	Mean height (mm)	Standard deviation (mm)	Standard error	Mean length (mm)	Standard deviation (mm)	Standard error	N
1957							
8/29	15.2	6.8	0.67	13.7	5.8	0.57	103
9/27	23.1	8.0	0.73	20.6	6.8	0.62	120
10/29	27.5	7.8	0.76	23.0	6.5	0.63	110
11/29	28.5	8.0	0.80	23.6	6.8	0.68	105
1958							
4/17	27.3	7.6	0.75	21.6	6.2	0.62	102
5/2	27.5	7.6	0.75	21.7	6.5	0.64	103
6/2	30.4	7.4	0.66	23.9	6.2	0.56	124
7/3	36.7	8.9	0.86	30.1	7.7	0.74	108
8/5	50.3	8.9	0.88	39.9	7.7	0.77	102
9/5	63.4	11.1	1.09	48.1	8.3	0.82	103
10/3	66.7	11.9	1.17	48.4	8.8	0.86	104
11/5	66.6	11.4	1.12	48.2	8.5	0.83	103
1959							
10/6	88.5	12.0	1.70	56.5	6.8	0.95	50

The suspended oysters continued to grow at a rapid rate during 1958. By the end of the year the mean height was 66.7 mm, an annual increase of 38.2 mm; and the mean length was 48.4 mm, an increase of 25.8 mm. Because growth was so rapid the shells were very thin and fragile; the average thickness along the principal axis was only 1.4 mm. In order to let their shells thicken, the raft oysters were planted on the bottom on November 13, 1958.

There was a decrease in the rate of growth in 1959 as compared to 1958. By the end of 1959 the experimental oysters' height and length were 88.5 and 56.5 mm respectively, an annual increase of 21.8 mm for the former and 18.1 mm for the latter. The shells of these oysters had thickened over threefold after being planted on the bottom and they now averaged 4.6 mm along the principal axis.

As shown in Fig. 4 the growth curves for height and length are very similar. Shell growth took place from April to September inclusive (Fig. 4 and 5). In 1958, 83.8 and 90.4 per cent of the annual growth

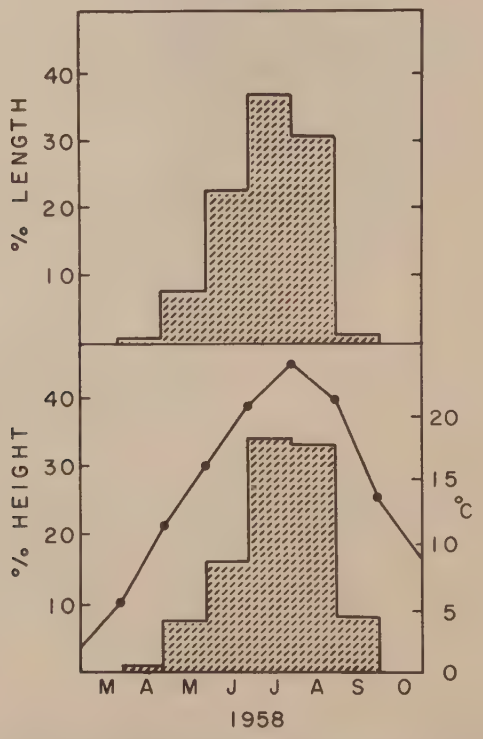

Fig. 5. Monthly percentage increment in height and length of raft oysters, 1958. Temperature curve based on records taken at time of measurement.

in height and length occurred during the months of June, July, and August. The water temperature during this period was above 15C (Fig. 5). In 1958 new shell was not observed until April when the water temperature approached 10C. By October the water temperature had fallen below 10 C and all measurable growth in height and length had ceased.

When the oysters were two years old, a considerable variability in size was observed. The largest oyster measured 109.1 mm by 57.0 mm and the smallest 66.5 mm by 49.6 mm. Still, four out of five were acceptable for the half-shell market. Local oystermen reported that the flavor of the oysters was excellent. The percentage of solids and index of condition for 50 raft oysters sampled just prior to being sold were 16.0 and 12.2, respectively.

The estimated mortality among the oysters suspended from the raft after one year, based on 14 of 79 oysters dying on one string, was 17.4 per cent. After a year on the bottom a sample was collected in order to determine the mortality which had occurred since planting. Of 87 oysters examined, 64 were alive and 23 were dead, or annual mortality on the bottom was 26.4 per cent. Therefore, the estimated total natural mortality for the two years was 39.2 per cent.

A local oysterman had planted 400 bushels of seed oysters in 1956. No effort was made to control the predators or protect the oysters while they were on the bottom. By the fall of 1958 approximately 90 per cent were dead. It therefore appears that suspending the oysters on the raft for one year had increased survival sixfold, if the estimates were valid.

The total cost of materials and labor to construct the raft and market the oysters was estimated at $248 (Table 2). Twenty-five bushels of raft oysters (averaging 250 per bushel) were sold and seven bushels were replanted. The value of these 32 bushels, at the present Chatham price of $11.50 per bushel, is $368. There is, therefore, a profit of $120 for this small scale operation.

DISCUSSION AND CONCLUSIONS

The results of this preliminary study are promising. The fact that it took only two years for seed oysters to reach market size is significant. Normally the Cape Cod oysters reach market size in four to five years. During this time they are at the mercy of drills, whelks, and other enemies which in their natural habitat can destroy over 90 per

Table 2. Total cost of material and labor to construct a two-log raft, to prepare the strings, and to market oysters

Materials:		
Two 25-foot cedar logs	$ 30.00	
Polyethylene tubing used for spacers ($23.75/1,000 feet)	16.00	
Copper paint ($7.75/gallon)	15.50	
Two 50-pound mud anchors ($18.50/anchor)	37.00	
Miscellaneous (rope, peavie, staples)	10.00	
Commercial spat ($1.50/bushel)	30.00	
Total costs for material		$ 138.50
Labor: (Chatham $1.50 hourly wage)		
2 hours cut and straighten wire	$ 3.00	
8 hours cut polyethylene tubing	12.00	
4 hours paint and staple logs	6.00	
36 hours assort, put in holes, and string shells	54.00	
3 hours to moor raft and secure strings	4.50	
4 hours to disassemble raft and plant oysters	6.00	
16 hours to tong, cull, and pack oysters	24.00	
Total costs for labor		109.50
Grand total of materials and labor		$248.00

cent of the young oysters in just two years. By suspending the seed during the first year of life the losses can be reduced to probably less than 40 per cent.

Our experiments were carried out on a small scale with one raft capable of supporting the weight of 25 to 30 bushels of one-year-old oysters. It should now be repeated on a larger semi-commercial scale either by private oyster growers or by State authorities. Either of these groups could establish a pilot oyster farm in order to ascertain the commercial practicability of raft culture in Massachusetts. There are many salt water ponds along the Cape Cod shores where such a farm could be established.

It appears certain that unless drastic changes take place in the methods of oyster culture now practiced in Massachusetts, the oyster industry of this state is doomed. The development of raft culture on a self-sustaining basis might be one answer to the present decline.

In conclusion, it must be realized that this study was conducted in Cape Cod waters and that other areas might give different results. It would be of interest to repeat these experiments in more southern waters.

I would like to thank the shellfish warden, selectmen, and oyster growers of Chatham, Massachusetts. Without their cooperation and help this study would not have been possible.

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Zooplankton, A Rich Fauna for High School Research

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The waters around us, fresh water or marine, abound in organisms quite suitable and interesting for biology projects and laboratory work. This article gives precise directions for the collection and study of this material. The author is a former contributor to these pages when a high school teacher in New England. He is now with the Biological Laboratory of the U.S. Bureau of Commercial Fisheries of the Department of Interior in Honolulu.

Introduction

Perhaps the best advice we can give the youngster who is motivated to inquire further regarding the selection of suitable science fair project material is to avoid the "one shot" demonstration approach which far too often results in a diagram depicting the frog circulatory system or the multi-colored artistic panorama of reds and whites illustrating tooth structure. The interested youngster should be encouraged to select a subject for study which will provide an opportunity for literature familiarization, sample and data collection, analysis, and final reporting of results. A project of this type will require preparation well in advance of the last hectic week before science fair time.

The present report is concerned with zooplankton fauna, which though abundant, may be a somewhat unfamiliar source of science project material. Zooplankton is a term used to denote a variety of small, weakly swimming adult or immature animals, whose large-scale horizontal distribution is dependent on water movement. Several marine zooplankters are shown in Figure 1. Zooplankton is present in nearly all rivers, ponds, lakes, streams, and in near as well as offshore environments. In addition, zooplankton can also be found in puddles, springs, tree-holes, and even horse tracks where water may collect temporarily. Zooplankters occupy a variety of niches and reflect sharply environmental differences in salinity, pH values, temperature, light, water circulation, and other measurable physical factors. Major animal groups likely to be present in most tow-net collections from suitable bodies of water are: (groups with asterisk are found in marine waters only).

Coelenterata
Siphonophora*
Medusae
Chaetognatha*
Rotifera
Annelida
Arthropoda
Copepoda
Cladocera
Ostracoda
Euphausiacea
Amphipoda
Mysidacea
Decapoda
Crustacean Larvae
Mollusca
Gastropoda
Pelecypoda
Cephalopoda*
Tunicata*
fish eggs and larvae

Collectively these organisms occupy a vital link in the food chain of the aquatic environment. They serve as grazers on the minute floating algae (phytoplankton) which synthesize starches, carbohydrates, fats, and proteins from the energy provided by sunlight and dissolved nutrient substances in water. Zooplankters in turn are preyed on by larger organisms, such as fish, most of which are not equipped to strain phytoplankton and would therefore perish were it not for the food concentrating activity of zooplankters. In addition to providing a vital source of food to various larger predators, zooplankton includes the larvae of many commercially important organisms, including shrimp, crabs, clams, lobsters, squid, octopus, and fish.

There are many ways of studying zooplankton. Collecting equipment can range from elaborate devices for continuous quantitative sampling from a boat underway to a small net cast from shore and reeled in with a fishing outfit. Determination of the quantity of plankton present in the water can be made with a flowmeter or simply by pouring measured amounts of water through a strainer. Many zooplankters can be kept alive

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readily for observations of their behavior. Students observing living plankton for the first time, particularly copepods and other invertebrates, will be astounded by the variety of shapes, brilliance of body coloration, and elaborate forms of appendages modified for feeding, swimming, and reproductive purposes.

The type of project outlined below is designed to parallel the kind of work often done in fishery investigations to determine the seasonal or areal abundance of fish forage, fish eggs and larvae, or organisms which may be indicators of limnological or oceanographic conditions. It presupposes a large class with access to fairly elaborate equipment, doing the field work as a group under the supervision of their teacher. With several modifications less ambitious zooplankton projects could be devised to fit other conditions.

Project Outline

The determination of the seasonal abu dance of various zooplankton constituer including fish eggs and fish larvae, fr surface waters of several selected nearsh areas should provide useful information, p ticularly if the study were undertaken in area supporting or adjacent to a sport commercial fishery.

Expected Results

From the series of data resulting from weekly or monthly sampling trips over six or eight-month period, it should be p sible to determine:

1. The average weight (standing cro of zooplankton during the period investigation, expressed in g/1,000 of water.
2. Seasonal variation of the standing z

Figure 1. Several members of the marine zooplankton, magnified 17 times: (top) fish larva; (center, left to right) copep *Pontella* sp. and *Pleuromamma* sp.; (middle right and lower left) shrimp (order Mysidacea); (lower center to right) egg and pelagic mollusk (tribe Heteropoda).

ure 2. Sampling gear: (left to right), detachable rear of plankton net (cod-end), Plexiglass water sampling bucket, jar ontaining powdered borax for neutralizing formalin, 16 oz. glass jars for storing zooplankton catch, glass jar with axed stopper for storing water collected for chemical analysis, bucket-type thermometer, flowmeter (side view); 45 m (diameter) plankton net, showing flowmeter in towing position, supported by three bridles; plankton log sheet, oreground) swivel attachment to allow for free rotation of plankton net during the tow.

plankton crop, expressed in g/1,000m³.

3. Months of greatest spawning activity of most common fish or other animal species, as indicated by increases in egg and larvae abundance expressed as numbers of eggs and larvae per 1,000m³.
4. Fluctuations in abundance of various members of the family of zooplankters selected for study (numbers of species per 1,000m³).
5. Relation between fluctuations of zooplankton abundance and measured environmental physical factors, such as temperature, oxygen, salinity, light intensity, and others.

Gear Requirements and Suggested Sampling Methods

1. Sampling gear required (Fig. 2).
   a. Access to sampling platform (an outboard-powered boat, or a pier or bridge over rapidly flowing water).
   b. 45 cm (diameter) plankton net with mesh aperture widths of approximately 0.4 mm.
   c. Flowmeter; essential for quantitative estimate of amount of water strained. (May be purchased from: Atlas Compass and Manufacturing Company, Vashon, Washington, or Rigosha and Company, Ltd., Kajicho 1-Chome, Kanda, Chiyoda-Ku, Tokyo, Japan: approximate cost $30.00).
   d. Bucket thermometer.
   e. Several dozen 6 oz. glass bottles, caps, and waxed cork stoppers to store water collected for chemical analysis of oxygen, salinity or other variables.
   f. Several dozen 16 oz. screw cap jars containing enough concentrated formaldehyde solution (40%) to give a 10% formalin solution with the addition of zooplankton sampie and water.
   g. Powdered borax; a teaspoonful should be added to each sample to neutralize the formalin preservative.
   h. Mimeographed plankton log forms

to record date, time tow began and finished, flowmeter reading, area, name of observer.

2. Time of tow: should be uniform for all collections, as many plankters carry out a diurnal vertical migration.
3. Method of tow: ideally during the tow the top of the plankton net should be positioned just beneath the surface film and as far outboard as practical of sampling platform (vessel or dock).
4. Duration of tow: adequate towing time should be allowed to capture a representative sample of the biota. The exact towing time will depend on local conditions. However, all tows should be of uniform length.
5. Method of collecting and preserving plankton catch:
   a. Calibrate flowmeter to determine number of revolutions per measured meter distance. See laboratory methods, section 2a.
   b. Secure cod end (detachable collecting jar or brass cup) to rear of net.
   c. Turn all flowmeter dials to " position.
   d. Attach net to towing line and co mence tow; record beginning ti in plankton log.
   e. At end of towing period retrie net, note time of retrieval and me reading on plankton log. Spec care should be taken in readi meter wheel as dials rotate in d ferent directions.
   f. Wash all zooplankters adhering sides of net into cod end, remo cod end and wash contents into oz. plankton jar (or more than o jar if needed) containing 40% for aldehyde solution and fill wi water.
   g. Add ½ teaspoon of borax to t preservative and deposit a label the jar.
6. During tow, collect a surface wa sample and record the temperature.
7. Materials required for sample analy (Fig. 3):

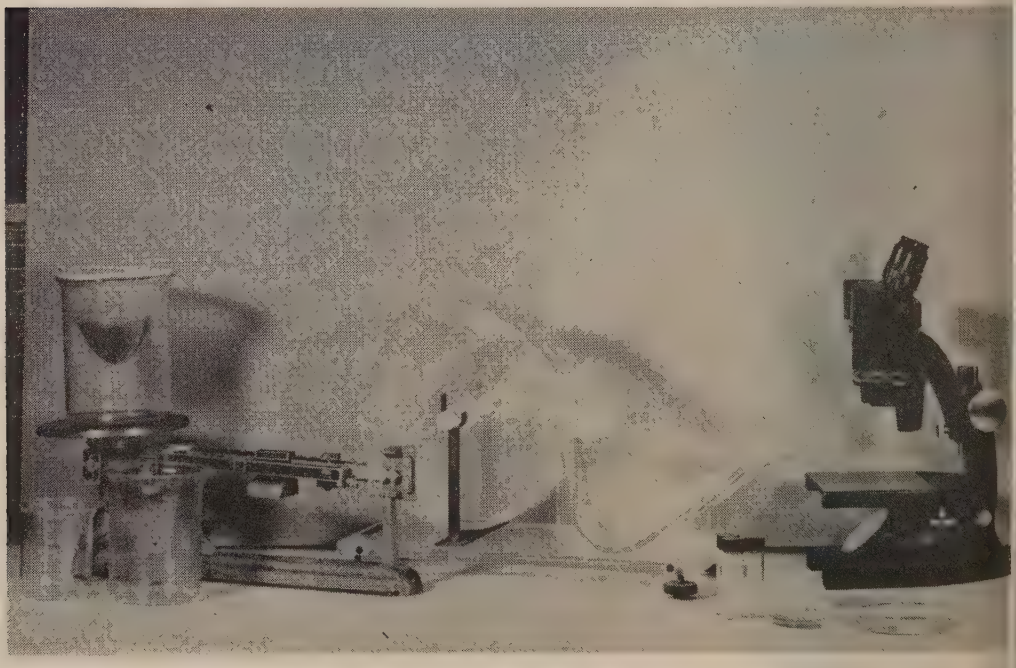

Figure 3. Material required for sample analysis: (left to right, foreground) glass beakers, vials for holding various plankters (4 dram size), glass watch-dish for use in separation of individual species from other zooplankters, petri (marked off in 1 cm divisions) for examining portion of aliquot and sorting sample; background, left to right, g balance scale with beaker containing zooplankton in draining sock, plankton aliquot sample divider, and binocular secting microscope (10x, 15x, 20x).

a. Assorted glass beakers, (25, 50 and 100 mls).
b. One dozen watch glasses.
c. Several dozen 4-dram vials for storage of various specimens.
d. One dozen petri dishes: used for sorting zooplankters under the microscope. The dish should be marked off into 1 cm divisions for ease in examining samples.
e. Binocular dissecting microscopes (10x, 15x, 20x), probes, and forceps.
f. Sample divider. In many instances the entire sample will contain far too many organisms for efficient examination. Divide sample into aliquot portions or stir the sample well and remove a known representative quantity of zooplankters with a pipette.
g. Gram balance scale.
h. Zooplankton draining sock with aperture openings of approximately 0.4 mm.

Laboratory Methods

Determine weight of individual zooplankton sample.

a. Wash sample into draining sock. At this time it is well to remove all organisms over 5 cm in length and not include their weight in the calculation. These larger organisms will be captured occasionally and inclusion of their weight will give a false value for the standing crop of zooplankton. However, note numbers and types of organisms removed.
b. Allow to drain for five minutes.
c. Weigh sock, contents, and beaker on gram balance and record weight.
d. Wash zooplankton from sock into another beaker.
e. Weigh wet sock and beaker and subtract total from previous weight to determine total weight of zooplankton (to nearest 0.1 of a gram).

Determine weight in grams/1,000 m^3 using the following ratio:

$$\frac{\text{weight of zooplankton in grams}}{\text{amount of water strained } m^3} : \frac{x}{1000\ m^3}$$

with x = wt in g/1,000 m^3 of water.

The amount of water strained (m^3) is found by determining the following:

a. Average revolutions of flowmeter per meter over a standard towing distance (average of 3 or 4 runs)

$$= \frac{\text{grand average (meter revolutions)}}{\text{length of course in meters}}$$

Example:

$$\frac{1834 \text{ (grand average)}}{640 \text{ (length course m.)}} = 2.866 \text{ rev./meter}$$

b. The meter factor for 45 cm nets, which is needed to calculate the amount of water strained by the net, is determined by the following method:

$$\frac{0.159\ (m^2, \text{ area of 45 cm net})}{\text{average rev. per meter distance}} = \text{meter factor}$$

Example: $\frac{0.159}{2.866} = .055$

c. Meter factor x total number of revolutions of flowmeter = amount of water strained, in m^3.

3. Separation of major zooplankton constituents.

a. After weighing, wash the total zooplankton sample into an appropriate size beaker.
b. Remove either an aliquot, using plankton sample divider, or a known portion by means of a pipette. Take care to stir the sample well to eliminate any bias of small over large organisms, since the larger have a faster settling rate than the smaller.
c. Remove all members of the family of organisms selected for study by pouring the aliquot into a small petri dish marked off into 1 cm divisions for ease in separation of individuals from other plankton constituents. The individual plankters can be picked out most easily using a binocular dissecting microscope (10x, 15x, 20x) and transmitted light.
d. Calculate numbers of organisms per unit of water strained (computation is simplified and more reliable if an aliquot portion of sample was examined, following the computation presented in laboratory methods, section 2).

e. Record observations on mimeographed data sheets for later analysis.
f. Deposit individual species into vials, label, catalogue, and store.

Individual students should be cautioned not to attempt the species identification of more than one family of any single group of zooplankters. Identification to species is a most difficult task requiring detailed study of the morphological characteristics on which classification is based. Because the literature containing adequate descriptions of various groups of organisms is widely scattered, considerable library time should be allowed for searching for authoritative references. For additional information, serious students should be encouraged to contact specialists in the scientific community, particularly for corroboration of species identification.

When attempting to separate species the student will gain some insight into the dynamic process of evolution in living organisms. He will find many individuals similar in form to published descriptions and, if he is observant, should uncover individual differences, some slight, some great. Here he will meet with his first joust in the great arena of taxonomic subjectivity, where those modern combatants, the "splitters" and the "lumpers," fight on *ad infinitum*. Here too the student will be rewarded with the realization that biology is dynamic and exciting and that the published word may indeed be open to question and debate in the light of new information.

In some schools limitations of equipment, facilities, and time may not allow for the type of zooplankton study outlined above. Other studies could be centered on laboratory observations of living zooplankton. Many zooplankters, particularly copepods, can be kept alive for weeks in aerated beakers, when supplied with adequate food, during which time observations could be made on swimming, feeding, and reproductive behavior (Cannon 1928, Gauld 1951, Marshall and Orr 1955, Conover 1956, and Lewis 1959).

With modifications in methodology, such as pouring measured amounts of water through an inexpensive net, rather than using flowmeters and large nets, the interested teacher should find that zooplankton fauna is readily collected and will provide eno variety and numbers of organisms for veloping a good number of well-rour student science fair projects.

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SEROLOGY OF ATLANTIC CLUPEOID FISHES*

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Fishes of the family Clupeidae are of world wide economic importance, and form a major link in the dynamic chain of marine life. The five dominant species of clupeoids in the western North Atlantic are: alewife (*Alosa pseudoharengus*), blueback herring (*Alosa aestivalis*), American shad (*Alosa sapidissima*), Atlantic herring (*Clupea harengus*), and Atlantic menhaden (*Brevoortia tyrannus*). All occur abundantly in inshore waters and three species, alewife, blueback herring and American shad, are anadromous.

Biological investigations of these species have provided much valuable information, but there are persistent problems associated with intraspecies groups. More precise information is needed about the existence and discreteness of subpopulations within species. Recent advances in the understanding of fish blood-group antigens (Suyehiro, 1949; Cushing, 1952, 1956; Cushing and Durall, 1957; Ridgway, 1957; Suzuki, Shimizu and Morio, 1958; Sindermann and Mairs, 1959; Ridgway, Cushing and Durall, 1960; Ridgway and Klontz, 1960; Sindermann, 1961b; Sprague, 1961; Suzuki, 1961), have suggested a potential major role of serological or immunogenetic studies in solution of such problems.

This paper summarizes findings from serological examinations of Atlantic clupeoids, carried on since 1957 at the U. S. Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine. Details of techniques and complete data may be found in Sindermann and Mairs, (1959, 1961), Sindermann (in press). Of particular concern are attempts to recognize by quantitative studies of erythrocyte antigens, subpopulations within two species, Atlantic herring and alewife. A comparison of five clupeoid species with a variety of serological methods has also been included.

ATLANTIC HERRING SUBPOPULATIONS

Information about subpopulations of Atlantic herring has been gained with a blood group system described earlier as the C system (Sindermann and Mairs, 1959). Antisera, prepared by injecting herring erythrocytes into rabbits, were used to test cells from individual fish. Cells of some herring clumped or agglutinated very weakly with such antisera, while cells from other herring reacted and agglutinated strongly, even in high dilutions of the antisera. This suggested that some individuals possessed a factor (an

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antigen) on their red cells that other individuals lacked. This factor or antigen was labelled "Antigen C" and fish were characterized as C-positive if they possessed the antigen, or C-negative if they lacked it. The antisera were further refined as reagents for detecting antigen C on herring blood cells by absorption with C-negative cells. Normal lobster serum, extracts of certain varieties of lima beans, and dogfish antiherring serum also differentiated C-positive from C-negative fish.

Blood samples from immature herring taken along the Maine coast were tested for antigen C frequencies. Tests of over 2000 individuals demonstrated population heterogeneity, and disclosed the existence of two subgroups, eastern and western, probably drawn from different spawning populations. Known major spawning populations (Georges Bank and Nova Scotia) were then tested for the frequency of this antigen, in an attempt to relate the immature sardine-size fish to spawning populations. A simultaneous one-year study of antigen frequencies in a laboratory population of immature herring disclosed no differences attributable to increasing age. Antigen frequencies in samples of adult fish indicated that both of the major known spawning populations in the Gulf of Maine could contribute to eastern sardine herring stocks (figure 1). Since the frequencies of antigen C were lower in western stocks than in either major spawning group, the tests indicated that at least part of the western sardine herring stocks was derived from a spawning source not yet sampled. Blood samples from adult herring have since been obtained from the Gulf of Saint Lawrence, and from the Rhode Island and New Jersey coasts, but none had the relatively low antigen frequencies of the western immature herring. Recently a small sample

FIGURE 1. Antigen C frequencies in adult and immature herring from the western North Atlantic.

of inshore spawners from the southern Gulf of Maine was tested and was found to have a low frequency of C-positive fish. This suggested an inshore source of western sardine herring stocks but additional sampling is necessary to confirm these results.

Another system was needed that would differentiate between the two major Gulf of Maine spawning populations—Georges Bank and Nova Scotia, since the frequencies of antigen C would not. By injecting rabbits with herring cells that were negative with the C reagent, antisera were produced that would differentiate, after absorption with cells of individual herring, another antigen with reactions apparently independent of the C system. The frequency of this new antigen, tentatively called "D," was found to be higher in the Georges Bank population. Preliminary tests of eastern sardine-herring stocks disclosed a low frequency of the D antigen, characteristic of Nova Scotia spawners rather than Georges Bank spawners. Much more sampling is needed, and better definition of D reagents is necessary before conclusions can be reached about the origin of eastern stocks.

This study of herring blood-group antigens has indicated that we should consider our Gulf of Maine sardine herring stocks as two separate entities. Other approaches to the definition of Gulf of Maine herring stocks have provided supporting evidence for serological findings. Studies of ocean currents (Bumpus, 1960) in the Gulf provide a physical basis for the existence of two subgroups of herring, and studies with parasite tags (Sindermann, 1961a) have indicated the same subdivision of immature fish suggested by antigen C frequencies.

ALEWIFE SUBPOPULATIONS

Alewives spawn in many rivers and streams along the Atlantic coast, from Virginia to the Gulf of Saint Lawrence, and spend much of the rest of their lives in the sea. As a logical expansion of subpopulation studies of herring, exploratory serological studies have been made that could eventually provide information about the discreteness of alewife spawning populations, the extent of straying to adjacent streams, and the movements of various age groups during their oceanic life.

Marked individual variations in agglutination of alewife erythrocytes occurred when such cells were tested with extracts of several varieties of lima beans. Reactions with cells of one fish could be as much as five doubling dilutions different from those of the next fish. Attempts to absorb the extracts with cells of individual alewives have been unsuccessful so far, but unabsorbed extracts have been used in quantitative studies with a scoring system comparable to that used by Ridgway, Cushing and Durall (1960) with Pacific salmon, and Race, Sanger and Lehane (1953) with humans. Samples obtained from four major spawning rivers were tested with an extract prepared in quantity from one variety of lima beans. Large differences in frequencies of fish negative at all dilutions of the reagent were found among the spawning populations tested (figure 2). Such differences suggest genetic heterogeniety among the spawning groups sampled. No

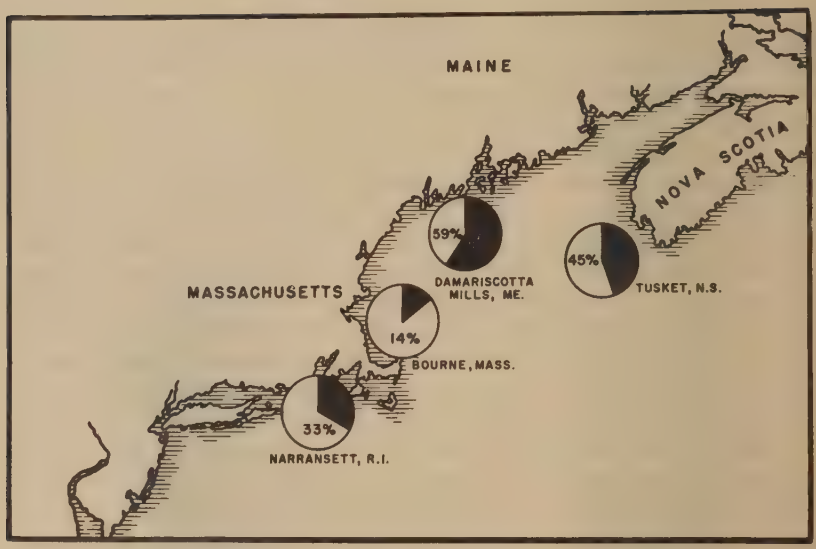


FIGURE 2. Frequencies of fish from four alewife spawning populations that were negative at all test dilutions of lima bean extract.

recognizable geographic gradients in frequencies of various types of reactions occurred, but only four out of many possible populations were sampled. A more definitive picture of the discreteness of spawning groups may emerge as more populations are studied.

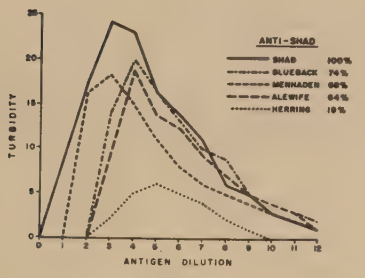
SEROLOGICAL RELATIONSHIPS OF FIVE SPECIES OF ATLANTIC CLUPEOID FISHES

Subpopulations within a species have been considered thus far in this paper, but serology can have a major role in solving taxonomic problems above the level of species as well. The five dominant clupeoid species of the western North Atlantic, alewife, Atlantic herring, blueback herring, American shad, and Atlantic menhaden, have been studied and compared. Blood samples were collected on the New Jersey coast, where all five species are represented. Serological relationships—the relative serological distances that presently separate species—were determined with a combination of several techniques, using both cells and serum.

Methods used were (1) precipitin tests visualized photoelectrically and by agar diffusion, (2) antiserum absorptions with species erythrocyte pools, (3) tests of individuals of each species with panels of anti-clupeoid antisera, (4) tests of individuals of each species with panels of plant extracts, and (5) electrophoresis. Of these methods the first two have produced most definitive results, although some of the others—particularly (3) and (4)—seem promising for future study. Examples of a few of the comparisons are presented in figure 3.

With a composite experimental approach, particularly with serum methods, alewives and blueback herring were found to be serologically very similar.

A



B

C

Antiserum	Cells used in absorptions	Agglutination reactions				
		Alewife	Blueback	Herring	Menhaden	Shad
Shad	Alewife	-	-	+++	+	++
	Blueback	+	-	+++	++	++
	Herring	+	-	-	++	++
	Menhaden	+++	++	+++	-	+
	Shad	-	-	-	-	-
	Unabsorbed	+++	++	+++	+++	+++

FIGURE 3. Illustration of results of species comparisons using (A) photoelectric scanning of precipitin reactions, (B) agar diffusion, (C) absorptions of rabbit antisera by species erythrocyte pools. In each case an anti-shad serum has been used. In (A) the similarity of curve areas derived from photoelectric scanning to the shad curve indicates degree of serological affinity. In (B) serological relationships are indicated by number and position of precipitate bands formed during agar diffusion. In (C) the antibodies remaining in anti-shad serum after absorption by red cells of other species indicate affinities. This figure is illustrative of the treatment given each species.

American shad were closer to the alewife-blueback herring complex than were Atlantic menhaden. Atlantic herring were serologically remote from the others. This composite method provides another criterion that can be used in taxonomic studies, along with morphological characters such as gill rakers, teeth, scale counts, and fin positions. It also supplies a method for distinguishing closely related species, many of which may be difficult to separate morphologically, especially in young stages.

SUMMARY

Species and subpopulation relationships of five Atlantic clupeoid fishes have been examined with a variety of serological approaches. Quantitative

studies of erythrocyte antigens have enabled distinction of geographic groups of Atlantic herring and alewives. Use of two erythrocyte antigens detected by absorbed antiserum has indicated that at least two major stocks of immature Atlantic herring exist in the Gulf of Maine. Hemagglutinins in plant extracts have been used to distinguish individual alewives, and quantitative studies of four spawning populations indicate genetic heterogeneity among the groups sampled. Serological relationships of all five clupeoid species have been determined with a variety of methods using serum and erythrocyte antigens. Immunogenetic methods offer a promising approach to taxonomic problems among the clupeoids and other teleost groups.

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ECOLOGICAL STUDIES OF *CRYPTOCOTYLE LINGUA* (TREMATODA: HETEROPHYIDAE) WHOSE LARVAE CAUSE "PIGMENT SPOTS" OF MARINE FISH

By

Carl J. Sindermann and Alva F. Farrin

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ECOLOGICAL STUDIES OF *CRYPTOCOTYLE LINGUA* (TREMATODA: HETEROPHYIDAE) WHOSE LARVAE CAUSE "PIGMENT SPOTS" OF MARINE FISH

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Inshore marine fishes are often liberally speckled with "pigment spots" or "black spots" caused by host response to larval trematode invasion. Along the northern New England coast sea herring (*Clupea harengus*) and other inshore fishes are subject to invasion by cercariae of *Cryptocotyle lingua* (Creplin), which develop in and emerge from the snail *Littorina littorea* (Figure 1). This European snail, and probably its trematode parasites, now abundant along the New England coast, were introduced in North America near the middle of the 19th century. Infective larvae of the most abundant parasite, *Cryptocotyle*, localize in the fins, muscles, or subepidermal tissues of fish. Pigment accumulates around the encysted worms, resulting in black spots. A

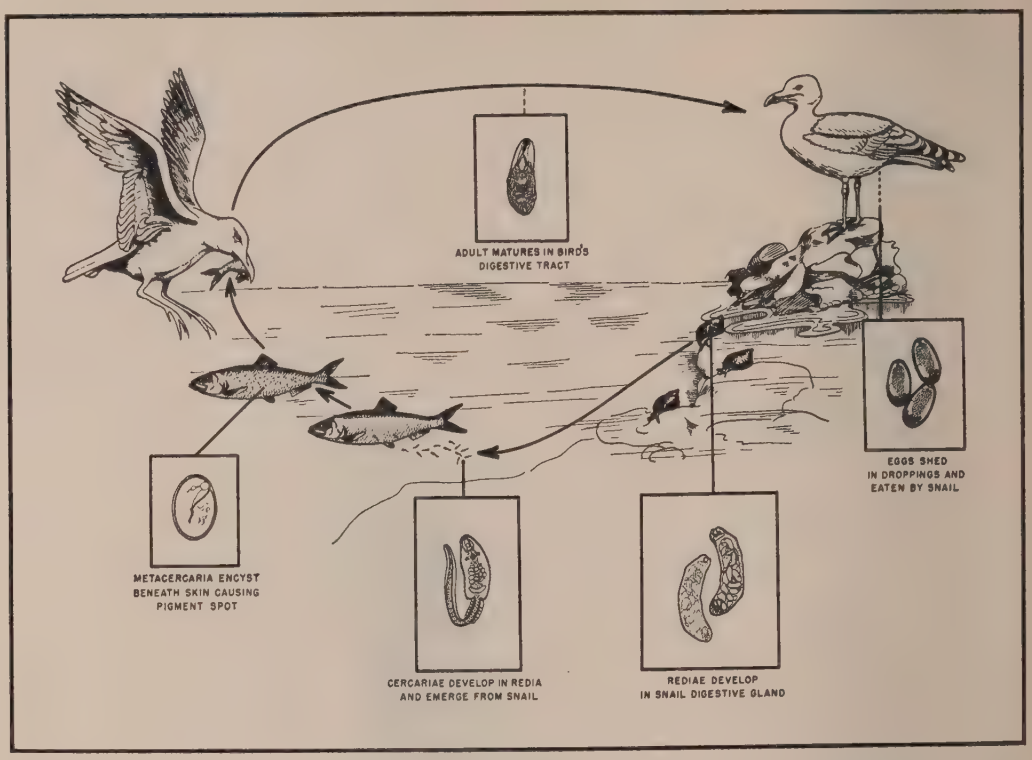
ADULT MATURES IN BIRD'S DIGESTIVE TRACT
EGGS SHED IN DROPPINGS AND EATEN BY SNAIL
METACERCARIA ENCYST BENEATH SKIN CAUSING PIGMENT SPOT
CERCARIAE DEVELOP IN REDIA AND EMERGE FROM SNAIL
REDIAE DEVELOP IN SNAIL DIGESTIVE GLAND

FIG. 1. The life cycle of *Cryptocotyle lingua.* Developmental stages have been redrawn from Stunkard (1930) and Christensen and Roth (1949).

previous study (Sindermann and Rosenfield 1954) disclosed that immature herring could be killed by massive experimental worm invasion—1-year-old fish in 15 days and 2-year-old fish in 30 days. Temperature was found to be important to cercarial emergence from infected snails; emergence declined below 12° C, and ceased below 10° C.

To assess the risk of infection for the fish intermediate host, studies of the abundance of snail infections and of environmental factors that may influence emergence of infective cercariae were considered necessary. The present paper, 2nd in a series on the role of parasites in the ecology of intertidal gastropods (Sindermann 1960), presents the results of a 2½-year examination of incidences of *Cryptocotyle* infections in the snail intermediate host. Seasonal studies have been made of cercarial maturation and emergence, as well as of variations in larval trematode incidences in snails from various tide levels. The influences of salinity, temperature, and day length on cercarial emergence have also been studied experimentally.

METHODS

A small ledge island (Figure 2) near Boothbay Harbor, Maine was selected as a study area because it was close to the U. S. Bureau of Commercial Fisheries Biological Laboratory, was inhabited by gulls year-round, and had abundant *Cryptocotyle* infections in the most abundant gastropod, *Littorina littorea.* This island is completely submerged by spring tides (average tidal range at Boothbay Harbor is 2.7 meters). Collections of 100 snails were made monthly and often bimonthly from each of 3 tide zones (high, mid, and low). Snails were isolated for 24 hours

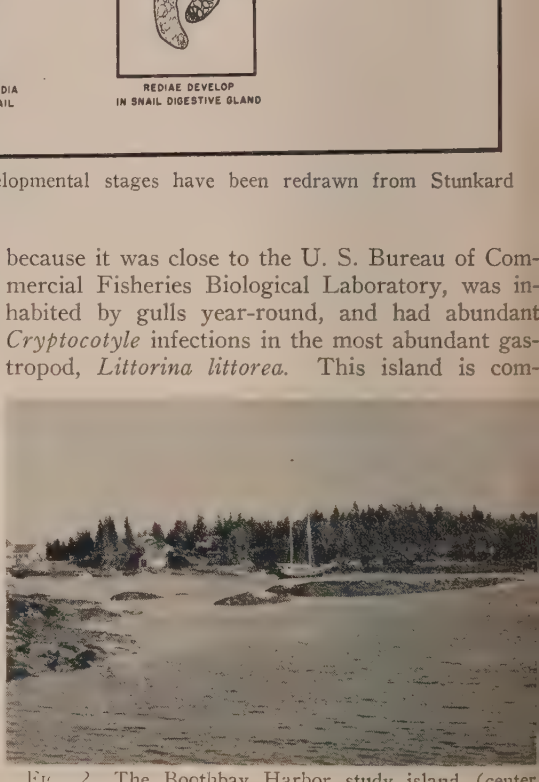

FIG. 2. The Boothbay Harbor study island (center right) at low tide.

n small jars of sea water partially immersed in xperimental tanks at the laboratory, and emergnce of cercariae at existing sea water temperaure was determined with a binocular dissecting icroscope. All snails were then crushed and ncidence of trematode infections determined icroscopically. Records were kept for each nail of sex, penis condition in males, presence or bsence of eggs in females, and stage of maturity f infection (especially whether or not fully-ormed and active cercariae were present).

To obtain information about possible movenents of snails from one zone to another, 600 nails were taken from the low-tide zone in Febuary 1958, painted distinctively with red enamel, nd returned to the site of collection. A similar umber were removed from the high-tide zone in eptember 1958, painted differentially, and reurned. Movements of such marked snails were oted and recorded monthly.

The effect of salinity on cercarial emergence was etermined experimentally by holding groups of nfected snails at summer sea water temperature 14-17° C) in 5 salinities ranging from 6 ‰ to 0 ‰. Cercariae were counted daily for 2 nonths. The influence of temperature on cercarial mergence was studied in 3 experiments conducted n December 1956, and January and February 957, in which snails with immature infections ere transferred from winter sea water temperaures (0°-4° C) to sea water warmed to 16-20°C. ercarial emergence at 16-20° C was checked aily for 1 month in each experiment. The posible effect of day length on maturation of inections and on cercarial emergence was exmined by maintaining groups of infected snails t seasonal sea-water temperatures and an exerimental 1-hour tidal cycle from January to lay 1959, subjecting one group to an 8-hour rtificial day length, one to a 16-hour artificial day ngth, and a control group to normal seasonal aboratory illumination. In a separate experiment, roups of infected snails were kept in constant arkness and in constant light at seasonal sea ater temperature for 2 months (July and Aust 1958) and examined weekly for maturity of nfections and cercarial emergence.

Seasonal Variations in Trematode Incidences

Monthly data from 2½ years of sampling January 1958-July 1960) in each of 3 tide zones re presented in Figures 3, 4, and 5. Included re graphs of (1) percentage infection in samples f 100 snails, (2) percentage of infections that ere mature, as indicated by fully-formed active ercariae in crushed preparations, and (3) periods

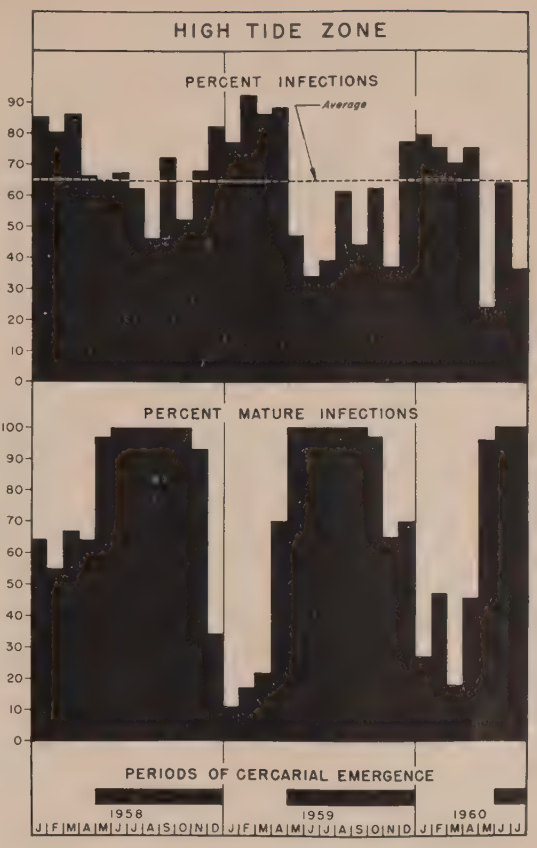

Fig. 3. Monthly incidence, maturity, and emergence data from high-tide zone samples.

of the year when cercarial emergence occurred from infected snails held at existing sea-water temperatures. Air and surface water temperatures for the period are presented in Figure 6.

Snails in the high-tide zone were exposed to air temperatures for most of each tide cycle. This is the zone where gulls congregate and where trematode eggs would be most abundant in droppings. The average high-tide zone infection for the entire study period was 65%, but marked seasonal variations occurred. Peak incidences occurred during the winter and early spring (December-April); reduced incidences characterized the warmer months. Mature infections were most abundant during the period when incidences were reduced (May-November); this was also the period when cercarial emergence occurred, although a few worms were released in December. Many marked snails migrated from the high-tide zone in late autumn and returned in early spring, while some remained in this zone throughout the winter. The winter period of relative scarcity of snails in the high-tide zone coincided with highest trematode incidence. Water temperatures reached

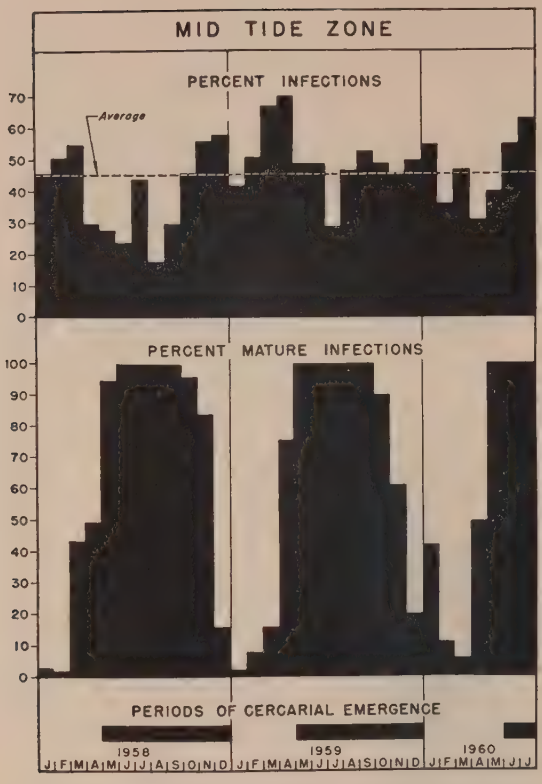

FIG. 4. Monthly incidence, maturity, and emergence data from low-tide zone samples.

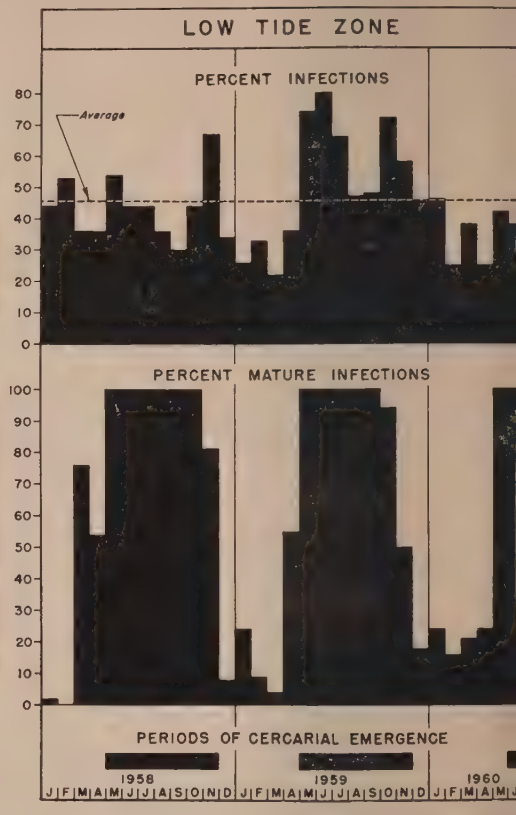

FIG. 5. Monthly incidence, maturity, and emerge data from low-tide zone samples.

a maximum in August or September, and a minimum in February; air temperatures were at a maximum in July, and minimum in February.

Snails in the mid-tide zone were exposed to air temperatures for roughly half of each tide cycle. The average mid-tide zone infection for the study period was 45%, markedly lower than the average for the high-tide zone. Seasonal variations in incidence occurred that roughly paralleled but were not as definitive as variations in the high-tide zone. Peak incidences occurred during the winter and early spring months. Mature infections were most abundant from May to November; this coincided with the period of cercarial emergence, except that a few worms emerged in December.

Snails in the low-tide zone were exposed to air temperatures only briefly or not at all during the tide cycle. The average low-tide zone infection for the study period was 46%, which was very similar to that of mid-tide zone, but much lower than the high-tide zone. Seasonal variations in incidence of *Cryptocotyle* infections occurred that tended to be reciprocals of variations in high-tide zone incidences, although the agreement was not exact. Infections were more numerous in low-tide zone snails during the warmer months of t year, and reduced incidences occurred in t winter. There was also an indication of spri and autumn peaks of infection in this tide zo Mature infections were most abundant from M to November; this coincided with the period cercarial emergence.

Incidence of infections, maturity of infectio and cercarial emergence gave evidence of s sonal influence. Seasonal changes in incide were most pronounced in the high-tide zone, w definite maxima in the winter. Low-tide zone cidences were usually reciprocals of high-t zone incidences, with maxima during the warm months. Mature infections constituted 90% more of recognizable infections from M through October in all tide zones, but decrea sharply during the winter months. More matu infections persisted through the colder mon in the high-tide zone than in lower zones (Dece ber-February averages: high-tide zone, 43%; m tide zone, 12%; low-tide zone, 11%). Cercar emergence from snails taken at all tide levels gan in May and continued through November low-tide zone, and into December in the mid- a

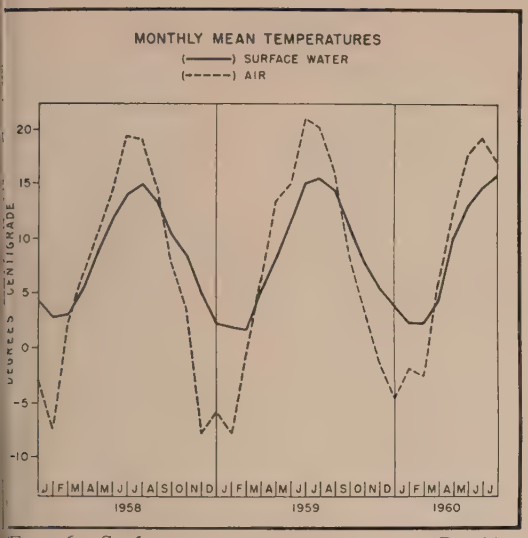

FIG. 6. Surface water temperatures at Boothbay Harbor, Maine, and air temperatures at Portland, Maine. (Portland is the closest Weather Bureau station, and monthly means agree closely with unofficial air temperature records kept at Boothbay Harbor.)

high-tide zones. No cercariae were released by any snail from January through April.

EXPERIMENTAL STUDIES OF FACTORS INFLUENCING CERCARIAL EMERGENCE

Knowledge of the incidence of larval *Cryptocotyle* in snails is a necessary first step in evaluating the risk of infection to the fish intermediate host, but incidence figures must be supplemented by studies of cercarial emergence, and the factors which limit or enhance it. Environmental conditions could affect emergence either directly (as in the case of temperature) or through seasonal physiological changes in the host. Since pronounced seasonal changes in maturity of infections and emergence of cercariae occurred, several environmental factors which vary seasonally were examined experimentally. Salinity, light, and temperature were selected although other environmental conditions may also play some role.

Salinity

Experimental variations in environmental salinity affected the rate of emergence of *Cryptocotyle* cercariae. Snails were maintained individually in salinities from 6 ‰ to 30 ‰ and emergence counted daily for 2 months (July and August 1959). Results are presented in Table I. Salinities below 18 ‰ caused a reduction in average daily cercarial emergence, and in the proportion of infected snails that released cercariae in any single day. Average daily inshore surface salinity at Boothbay Harbor for 1959 was 30.5 ‰, with a range from 16.7 to 35.0.

TABLE I. Effect of environmental salinity on emergence of *Cryptocotyle* cercariae

Salinity (‰)	Number of infected snails	Average daily % of infected snails that emitted cercariae	Average daily number of cercariae emitted per snail
30.....	14	81	670
24.....	14	81	580
18.....	13	86	570
12.....	11	51	210
6.....	11	16	3

Light

The role of light and day length in maturation of infections and emergence of cercariae is not clear and will require further experimental studies. Mature infections were most abundant during periods of longer day length, and Sindermann and Rosenfield (1954) reported that maintenance of infected snails in constant light or constant darkness during the summer reduced emergence of cercariae. Repetition of these experiments during the present study disclosed that not only did emergence decline, but that most infections had regressed so that after 2 months active fully formed cercariae could no longer be found in crushed preparations. Since most larval *Cryptocotyle* localize in the digestive gland of the host, the gross color of this organ is modified to dull grey while infections are mature, and to light brown when infections are immature. The normal grey color of the gland in all infected snails in summer was experimentally changed to the light brown winter color by the extremes of light used.

However, maturation and cercarial emergence in spring were not enhanced by artificially increasing day length to 16 hours from January to May. Emergence began in May from control snails held in an artificial 8-hour day length since January, from experimental snails held in an artificial 16-hour day length, and from snails held in normal seasonal illumination. Seasonal water temperature was used for each group.

Temperature

Temperature was important in governing maturation of infections and emergence of cercariae. Periods of abundant mature infections and cercarial emergence coincided with higher water temperatures; immature infections and absence of emergence coincided with low (below 10° C) water temperatures. Maturation of infections and emergence of cercariae were induced during winter months by maintaining infected snails for 3 weeks in sea water warmed to 16-20° C, with sea-

sonal illumination. Three separate experiments, one in December, one in January, and one in February, using snails known by cercarial emergence during the previous summer to be infected, gave comparable results. Sporadic emergence began as early as the 2nd week, with a majority of snails emitting cercariae by the end of the 3rd week. When results of this experiment are combined with negative findings reported above with artificially increased day length, it appears that temperature is a more important factor in the onset of cercarial emergence in the spring than is increasing light.

A comparable seasonal study of the avian schistosome *Austrobilharzia variglandis* (Sindermann, Rosenfield and Strom 1957) revealed that mature cercariae were present throughout the year, but emergence was completely inhibited by water temperatures below 6° C. Even in winter, emergence could be stimulated within 24 hours by elevation of sea-water temperatures above 12° C. However, *Cryptocotyle* infections in *Littorina* regress during the winter, so that a longer period of increased temperature is necessary before mature cercariae are present.

Discussion

Many factors may contribute to seasonal changes in incidence of larval trematode infections. Migrations of the snail host and possibly differential migrations of normal and infected snails may play an important part. Marking experiments during the present study have indicated that many snails migrated from high-tide zone to the mid- and low-tide zones in late autumn, and returned to the high-tide zone in early spring. Such migrations are known by commercial periwinkle collectors, since increased catches are made in colder months when snails aggregate in the low tide zone. Recent work in England (Smith and Newell 1955) indicated that *Littorina littorea* adapted to a particular beach level, but possibly this behavior is altered in northern New England by the severity of the winters. Principally from the reciprocal tendencies of worm incidence in high- and low-tide zones, there is some indication from the present work that *Cryptocotyle* infections tend to immobilize the host to the extent that it may not participate in seasonal migrations. Such a differential migration could account for several of the seasonal variations presented in this paper. Early winter increases in high-tide zone incidence might be due in part to emigration of uninfected snails, while spring increases in low-tide zone incidences might be due in part to departure of many uninfected snails from that zone.

The true sequence of events may be obscured, however, by development of new infections or seasonal changes in infectivity to the snail of t ingested miracidial stage. Also, seasonal var tions in gull infections with adult *Cryptocot* may occur. In the present study, a snail was co sidered infected only when trematode larvae cou be recognized in the macerated digestive gla with a dissecting microscope. With this meth immature infections were not found in snails fr any tide zone from June through September, in cating that the appearance of new infections w not a complicating factor during that period, though such new infections may cause importa incidence changes at other times of the year, pa ticularly late autumn and early winter.

Infection of *Littorina* with larval *Cryptocot* seriously reduces the reproductive potential of t population. The reproductive period as indicat by mature penis size in uninfected males and pr ence of eggs in uninfected females extended fr March to August. During this period, the per of infected males remained rudimentary, and eg were produced only very rarely by infected f males. An average of 52% of the snails composi the island population were infected, and th sterile, so parasitization constitutes a serious lim ing influence.

By combining results of field studies with e perimental work, it is possible to achieve a pictu of potential risk to inshore fish such as sea he ring. These fish are important second inte mediate hosts of *Cryptocotyle* in northern Ne England, and their movements correlate well wi data presented here on the parasite. Immatu herring usually move into coves and bays in M and remain in inshore waters until Novembe This coincides with the period of cercarial eme gence and maximum maturity of infections. Du ing this time herring schools are often very clo to shore and undoubtedly encounter areas of hi cercarial density. Samples from most commerci catches show the results of trematode invasion- some samples with many metacercariae per fis and some with relatively few. Pertinent relatio ships are graphed in Figure 7.

Results of this investigation have been instru tive, but there are still major gaps in our know edge of the ecology of larval *Cryptocotyle*. The may be seasonal, age, or geographic variations the habits and parasite incidences of gull popul tions that may cause seasonal or yearly variatio in snail infections. The period of the year and t age at which snails become infected, and the deve opmental time for such infections at various te peratures need further study. Also, local a coastwide geographic variations in snail infectio

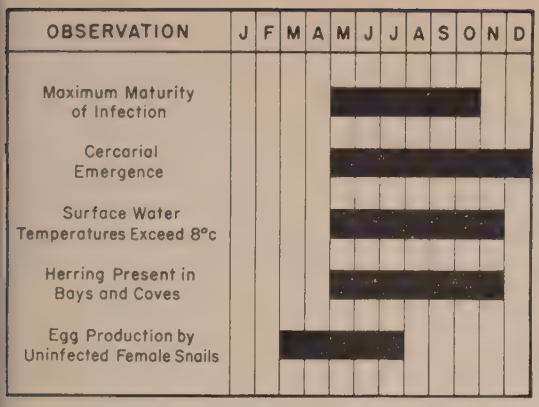
OBSERVATION
J F M A M J J A S O N D
Maximum Maturity of Infection
Cercarial Emergence
Surface Water Temperatures Exceed 8°c
Herring Present in Bays and Coves
Egg Production by Uninfected Female Snails

Fig. 7. Summary of seasonal phenomena related to the ecology of *Cryptocotyle lingua*.

must be examined to achieve better understanding of the effect of the parasite on inshore marine fish.

Summary

As part of a continuing study of the role of disease in the sea, examination was made of seasonal variations in incidence of larval *Cryptocotyle lingua* in the snail *Littorina littorea*. Descriptive work was supplemented with experimental studies of factors that might influence emergence of infective cercariae from the snail host.

Average incidence was highest in samples of snails from the high-tide zone. Maximum high-tide zone incidences occurred from December to April, while infections were most abundant in low-tide zone samples during the summer months. Mature infections were most abundant and cercarial emergence occurred in samples from all tide zones from May to December. Maturity of infections decreased sharply during the winter months, and no cercariae were released from January through April.

Environmental factors influenced cercarial emergence. Salinities experimentally reduced below 18 $^{0}/_{00}$ caused a decrease in average daily emergence and in the numbers of infected snails that released cercariae. Maturation of infections and emergence of larval *Cryptocotyle* were not enhanced by experimentally increased day length during the late winter, but maturation and emergence were induced during the winter by artificially increasing the water temperature for 3 weeks.

The seasonal changes in incidence and maturity of infections, and in environmental factors, form an interesting ecological association with migrations and habits of inshore marine fish such as herring.

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MEASUREMENTS OF A WHITE SHARK, *CARCHARODON CARCHARIAS*, TAKEN IN MAINE WATERS.—The white shark or maneater, *Carcharodon carcharias* (Linnaeus), is relatively uncommon in Maine waters, but unrecorded reports occur almost every summer. Scattergood, Trefethen, and Coffin (1951, *Copeia (4):297–8*), Scattergood and Coffin (1957, *Ibid. (2):155–*

Fig. 1. Female white shark, *Carcharodon carcharias*, captured near New Harbor, Maine, 20 July 1961.

Table 1. Measurements of a Female White Shark, *Carcharodon carcharias*, Taken in Maine 20 July 1961

	mm
Snout length in front of mouth	290
Snout to line drawn between anterior of nostrils	140
Snout to 1st dorsal fin	1,700
Snout to base of upper caudal fin	3,740
Snout to pectoral fin	1,180
Nostrils, distance between inner ends	180
Eye diameter	40
First dorsal fin, anterior margin	620
First dorsal fin, length of base	440
Second dorsal fin, anterior margin	130
Second dorsal fin, length of base	70
Anal fin, anterior margin	120
Anal fin, length of base	80
Caudal fin, upper margin	950
Caudal fin, lower margin	640
Pectoral fin, outer margin	910
Pectoral fin, distal margin	690
Distance between 1st and 2nd dorsals	1,050
Distance between 2nd dorsal and caudal	500

6), Scattergood and Goggins (1958, *Maine Field Nat. 14(2):40–3*), and Scattergood (1962, *Copeia* In Press) have documented several records in recent years. The condition of these fish after capture, and/or after a time lapse in notifying individuals capable of identifying the species, is often such that any detailed measurements cannot be made. A recent capture, though beheaded, was in generally good condition and measure were possible. The purpose of this n to compare these measurements with ously published information.

The specimen was captured on 20 1961 near Bar Island, off the souther of Loud's Island, in Muscongus Bay o coast of Maine. Sharks had been rep in this vicinity for several days previ The shark was first harpooned at 11:0 with a tuna "iron" and was eventually with a rifle (.30 caliber) in the early noon. The specimen was then broug New Harbor, Maine. At dockside, aft moving the stomach and liver, a photo was taken (Fig. 1). Most of the teeth then removed for souvenirs and the severed from the body to reduce the w for lifting.

I first saw the specimen at 10:00 PM o day of capture at the establishment of a dealer. Identification was determined evening, and measurements were mad following morning. The specimen w female, and total length (snout to t upper caudal lobe) was 4,500 mm (1

Fig. 2. Teeth of white shark, *Carcharodon carcharias,* taken in Maine, 20 July 1961.

weight estimated by experienced local rmen was 1,700 pounds. When the was eviscerated, the fishermen found nbryos and did not report any particular e of enlarged ovaries.

loration.—The back was black which d to gray on the upper sides and then nite on the lower sides and ventral sur- There was a black spot in the axil of ectoral. The top of the pectoral was and the underside white except that ip of the pectoral was black. The dorsal gray for the most part, but the margins outlined in black. The pelvics were on the anterior edge and faded to gray then white. The upper lobe of the al was black and dark gray, the lower white in the anterior portion and shaded ay and then black at the tip and pos- r portion. The second dorsal was en- black and the anal fin was white.

scription.—Measurements in mm and, in ntheses, proportional dimensions as per of total length are given in Table 1. e proportional measurements do not r greatly from those listed by Springer 9, *Copeia (2):115*) which are cited in low and Schroeder (1948, *Fishes of the rn North Atlantic. Sharks. Sears Found. Research Mem. (1):134*). His measure- s were from an immature female, 4,700 total length, taken in Florida. Scatter- good, Trefethen, and Coffin (*op. cit.*) listed measurements for a specimen 3,870 mm long which weighed 1,299 pounds. The proportional measurements compare favorably with those of the New Harbor specimen. Kenyon (1959, *Calif. Fish & Game 45(1):58–9*) reported on a specimen of comparable length (4,610 mm) from California which weighed more than 3,000 pounds. Proportional dimensions indicate that the fins of the California individual were consistently greater than either the Florida or Maine specimens, and reflect the heavier and broader features.

Several teeth were obtained and measured (Fig. 2). The largest, from the upper jaw, is assumed because of its size and configuration to be either the 1st or 2nd tooth. Its total height (including base) was 36 mm, from mid-base to apex 23 mm, and its greatest width at the base was 29 mm. The largest from the lower jaw, also assumed to be the 1st or 2nd tooth, was 40 mm in total height, 23 mm from mid-base to apex, and 31 mm at its base. Other teeth examined were considerably smaller; the smallest removed from the rear of the lower jaw measured 14 mm in total height, 7 mm from base to apex, and 15 mm at the base.—Bernard E. Skud, *U. S. Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine.*

Scientists Answer Questions On Herring Seining

(In an effort to supply Maine fishermen with sound information on purse seining for herring, we asked the Boothbay Laboratory to wrap up what is known about the herring fishery. The following report is based on information supplied by many scientists and gear research men. We consider it one of the most thorough and straightforward government articles we have ever seen and wish to extend our heartiest thanks to Mr. Skud and his capable team who obviously put much time and thought into its preparation. Ed.)

By Bernard E. Skud, Laboratory Director
U. S. Bureau of Commercial Fisheries Biological Laboratory
Boothbay Harbor, Me.

The recent winter use of the purse seine in Maine waters has attracted considerable interest among sardine fishermen and industry members. Many questions have been raised concerning this innovation in the sardine industry, particularly with regard to the effects that purse seining might have on the stocks supporting the fishery. Other questions concern the quality of pack and social and economic facets of industry operation.

These social and economic considerations are extremely important and should be weighed carefully by the industry itself. While all aspects of the fishery are of vital interest to the U. S. Bureau of Commercial Fisheries Biological Laboratory at Boothbay Harbor, the matter of supply and the possible influence of new gear on the abundance of fish is a distinct responsibility of our fishery scientists. We have been following this fishery very closely since it began in February and have collected samples from the various sardine catches for analysis.

To evaluate the effects of the winter purse seine fishery, we have two avenues of approach. One is the study of known facts about the Maine sardine fishery and the biology of the fish; the other is the review of other fisheries and their experiences with purse seining.

Both of these approaches provide information pertinent to the questions now at hand and are discussed in the following paragraphs.

The question most frequently asked is, "Will the purse seine seriously reduce the numbers of fish available for the summer fishery?"

To answer this question, we can turn to our studies on migration, stock identity, growth and catch records. The stop-seine and weir fisheries, because they are confined to inshore waters, do not lend themselves to analyses which will provide estimates of total numbers of fish, but our studies do provide information on abundance in relation to the amounts of fish captured in the fishery.

Our results indicate that the summer fishery removes but a small portion of the total number of fish available along the Maine coast ! !

MUCH EVIDENCE

What specific evidence is there to support this conclusion? The first is the result of tagging experiments. Considering the percentage return of tagged fish (2 to 6%) as representative of the percentage removed by the fishery in any one month, we can see that the take is not heavy.

When sardines are tagged in successive months, better than 90% of the recoveries are captured within 30 days and within a radius of 25 miles. These recaptures indicate that new segments of the total sardine population are contributing to the fishery throughout the fishing season. If the fish remained in the inshore waters, we would expect recoveries over longer periods of time and over more extensive areas of the coast.

We can infer that the greatest portion of uncaught fish eventually moves beyond the reach of the inshore gear, weirs and stop seines.

Further substantiation of the offshore movement is afforded through the examination of length measurements from fish taken during the summer. If a stock of fish entered the fishery in the spring o f the year and was available throughout the summer and autumn, we could expect an increase in average length. Our results, however, are quite different and in some instances show that the average length of fish caught in one month is less than that of the previous month.

For fish of the same year class, the explanation of this reduction in size is that different individuals are contributing to the fishery. Apparently, when the larger fish attain a given size, they move beyond the reach of the inshore fishing gear.

Results of our studies with biological types and blood groups have shown that there is a difference between sardines captured in eastern and western Maine. This difference is an important consideration with regard to total abundance of fish, for it is apparent that the fishery does not have to rely on a single stock of sardines.

Further, fish caught by purse seines during the winter extension have been examined and show a marked lack of biological types associated with inshore fish. This is at least suggestive of perhaps another stock — previously unfished — but will necessitate intensive study to verify such a possibility.

Through the cooperation of the fishermen, canners, and the Me. Dept. of Sea and Shore Fisheries, we have collected over 12,000 fish from the winter purse seine fishery. Preliminary examination shows that the fish averaged 6" in length and were born in the fall of 1960. Only one tagged fish from our inshore tag releases of 1961 has been recovered by the winter fishery; that fish had been released at Stonington on Oct. 10, 1961, and was recaptured on April 8, 1962, four miles southeast of Monhegan Island.

Experiences of other herring fisheries (Maine sardines are immature herring) which utilize purse seines provide information useful in the evaluation of our local situation.

The Norwegian fishery is a classical example. That fishery depends on the Atlanto-Scandian herring stocks which migrate annually from Icelandic waters to the coast of Norway. There are few restrictive measures and the stock is fished intensively by Norway, Iceland and Russia.

Since the introduction of purse seining, the catches have increased markedly and, on occasion, have reached a million tons. In spite of the increasing catches, Norwegian biologists in the early 1950's predicted a severe reduction based on changing natural conditions which would divert the herring from their familiar fishing grounds. This prediction has held true, and apparently the reduction is unrelated to the use of the purse seine.

In contrast to the Norwegian fishery, the Alaska herring fishery is one of the most strictly regulated fisheries. In addition to restricted areas, closed seasons and quota limitations, there are regulations governing the mesh size and length and depth of the purse seine gear.

This series of regulations has not provided a consistent supply of herring as one might expect, and apparently the environmental conditions and the response of herring to these conditions are the factors which govern the supply of herring.

A recent report of the International North Pacific Fisheries Commission states that an increased amount of fishing in Alaska would result in greater yields without endangering the future supply.

These examples of other purse seine fisheries suggest that natural conditions often dominate the patterns of fluctuations and that the role of man's fishing is not the controlling factor in these fisheries.

It is not intended to leave the impression that man has never had an adverse effect on a fishery.

(Continued On Page 4)

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Scientists

(Continued From Page 3)

On the contrary, fishery scientists, who perhaps coined the phrase "overfishing", can provide irrefutable evidence of such occurrences, but these scientists are also cognizant that failures in fisheries, as agricultural crop failures, are more frequently beyond the control of man's influence.

Further evidence of the effect of natural factors can be found in the drastic decline of the St. Lawrence herring fishery beginning in 1956. These reduced landings were directly related to natural mortality and not to any change in fishing effort. It is also interesting that the herring fishery for adults on the Nova Scotia coast last year was one of the largest on record, while sardines along the Maine coast were in short supply.

Our studies and the knowledge gained from other fisheries indicate that the utilization of purse seine gear in the Maine sardine fishery will not have an detrimental effect on the abundance of fish. Fishery scientists of the Bureau of Commercial Fisheries Biological Laboratory in Boothbay Harbor will follow and study the purse seine fishery very closely to document any change that occurs. These scientists are concerned with a continuing maximum yield of fish.

In this regard, the Maine sardine fishery has the advantage of harvesting immature herring, some of which would otherwise be lost through natural causes before reaching adulthood.

In summary, there is no basis from biological data now available for exclusion of the purse seine from the Maine sardine fishery. It remains for the industry to evaluate such factors as the quality of winter fish for packing, mobility and efficiency of purse seines and other economic factors.

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Experienced Canadians Join Herring Hunt Off Maine Coast

By F. S. Hadden

DEER ISLAND, N. B. — History is repeating itself but with certain alterations and improvements. Seiners have been going from Canadian side of the border to operate in the waters off the coast of Maine.

Early in the 1900's many people from this area, looking afield for more lucrative fishing grounds, went to various places from Machias Bay to Castine and there built weirs or operated shutoff's. Many were American citizens owning and operating boats under American registry. Some were Canadians who got by because some customs men of that day forgot to ask certain questions as to nationality and port of origin.

Today the trend is very definitely toward purse seining. This method has been followed for some years and with much success along the south coast of New Brunswick and in Nova Scotia, from Digby to Cape Sable. In Maine this method has been used to a limited extent and has not been developed to the high extent of efficiency as that of the New Brunswick seiners.

HIGHLINE CREW

Now, in an effort to improve the technique, Moses Pike of Lubec (Holmes Packing Co.), has purchased the seiner Wave Guide of Campobello and has employed Capt. Medford Mathews, also of Campobello, as seining expert and electronic technician.

Capt. Mathews is probably one of the best, if not the best, all-round seiner operating on this coast. Not only is he an expert in the actual seining operation, but he is also an expert in the repair, maintenance and operation of the many electronic devices now used in seining herring in both deep and shallow water.

At the same time Pike started his experiment, one of the Campobello seiners, the Sea Scanner, went west as far as Monhegan Island, but could only operate in an area which would be at least three miles from the nearest land and had to comply with the regulations of the American customs and Department of Fisheries governing the protection of territorial waters. Fisheries patrols from the Maine ports of Rockland and Boothbay Harbor were continually checking to see that there was no infraction of the law.

The first night the Sea Scanner was on the job 196 hogsheads of herring were taken and the second night 115. By this time Stan Savage, also of Campobello, arrived on the scene and is reported to have made at least one good set. After this other Campobello seiners appeared, but to use an expression of the late Capt. Newell Lord of the carrier Muriel, "They arrived the day after the fair." The herring seemed to have scattered.

All herring caught excepting 115 hogsheads were taken by Connors Bros. Ltd. of Blacks Harbor, N. B., in the boats Allan McLean, Carolyn Michael, Page and Roger and Louie. Some 115 hogsheads were taken by the Mary Ann and the Jacob Pike to the Pike plant at Rockland, Me.

BEST GOING

The Campobello purse seiners are probably the best anywhere on this continent. This writer has studied the methods used on the Pacific Coast and Newfoundland where weirs are unknown and where the bulk of herring is taken by purse seines and it is my opnion that those people could learn much from the techniques developed and put in practice by these fishermen from Campobello. Their knowledge in the handling of boats and seines coupled with a high degree of webfootedness — which takes them into the waters from Black River to Cape Sable in Canada and from Browns Banks to Cape Small Point in international waters — makes them very capable and productive herring fishermen.

Canadian weirmen seem to be expressing considerable interest as to how the Maine venture will turn out. How will the weir owners and shutoff seiners react? How will custom regulations deal with what in the old rum running days probably was called "hovering?" And above all, will the herring disappear from the Maine Coast as they have from the Bay of Fundy?

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Hearing Set May 2 On Law To Restore Fishermen's Benefits

WASHINGTON, D. C. — Hearings will be held here May 2 on legislation to restore medical care benefits to owner-operators of fishing vessels and other self-employed seamen under the Public Health Service Act.

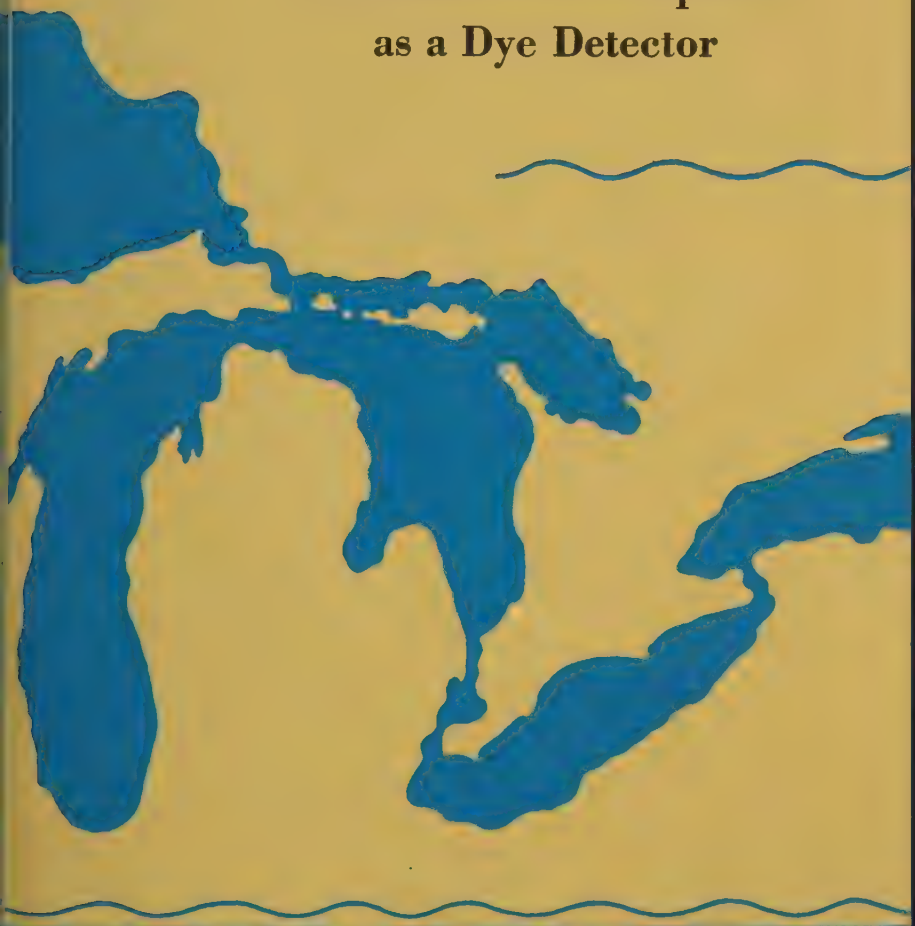
This announcement was made by Senator Magnuson (D.-Wash.) co-sponsor of the bill with Senator Bartlett (D.-Alaska). Senator Magnuson is chairman of the Senate Commerce Committee.

Magnuson said legislation would extend medical care in Public Health Service hospitals, outpatient clinics and other established service medical facilities to 6,000 to 11,000 seamen who have been ineligible for such benefits since 1954.

Seaman aboard registered or licensed vessels, who are not regular crew members but who perform useful services relating to the care, preservation and navigation of the vessels, would also be entitled to medical care benefits under the bill, Magnuson said.

Estimation of the Brook and Sea Lamprey Ammocoete Populations of Three Streams

A Photoelectric Amplifier as a Dye Detector



t Lakes Fishery Commission

ICAL REPORT No. 4
ıber, 1962

The Great Lakes Fishery Commission was established by the Convention on Great Lakes Fisheries, between Canada and the United States, ratified on October 11, 1955. It was organized in April, 1956 and assumed its duties as set forth in the Convention on July 1, 1956. The Commission has two major responsibilities: the first, to develop co-ordinated programs of research in the Great Lakes and, on the basis of the findings, recommend measures which will permit the maximum sustained productivity of stocks of fish of common concern; the second, to formulate and implement a program to eradicate or minimize sea lamprey populations in the Great Lakes. The Commission is also required to publish or authorize the publication of scientific or other information obtained in the performance of its duties.

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ESTIMATION OF THE BROOK AND SEA LAMPREY AMMOCETE POPULATIONS OF THREE STREAMS

by

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A PHOTOELECTRIC AMPLIFIER AS A DYE DETECTOR

by

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ESTIMATION OF THE BROOK AND SEA LAMPREY AMMOCETE POPULATIONS OF THREE STREAMS

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ABSTRACT

Marking experiments on three streams in the Upper Peninsula of Michigan yielded quantitative estimates of populations of larval and transforming lampreys. The estimates not only gave an idea as to the numbers of ammocetes in the streams, but also confirmed the judgments of abundance based on earlier surveys with electric-shocking equipment and provided valuable information on the movement of larvae during chemical treatment. The estimated numbers of ammocetes in the three streams were 4,300 in Furnace Creek, 30,600 in Snyder Creek, and 336,700 in the Ogontz River.

Introduction

The Bureau of Commercial Fisheries and the Fisheries Research Board of Canada, under contract with the Great Lakes Fishery Commission, have been using specific lamprey larvicides to control sea lampreys *(Petromyzon marinus)* in streams tributary to the Great Lakes since 1958 (Applegate, Howell, Moffett, Johnson, and Smith, 1961). In the course of stream treatments with these larvicides, it has been visually apparent that large numbers of lamprey larvae of various species were destroyed. Collections taken by fyke nets and dip nets during and after treatment revealed the larval composition by species. These samples provided no estimates, however, of the total number of lamprey larvae destroyed. Since most treatments are almost completely effective the number destroyed would approximate the original population.

The first attempt to estimate the size of the ammocete population in a stream tributary to the Great Lakes was made by Hansen and Hayne (1962) in the Ogontz River. Collections on which they based their estimate were made in the shallower areas by the introduction of larvicide into a circular enclosure 2.5 feet in diameter and in deeper water by orange-peel dredge. The study area was divided into 100-yard sections in which sampling stations were randomly placed. The estimate of larval population was the product of the mean number of ammocetes collected per square

foot and the total area. The estimate of the ammocete stock in the same stream, made one year later in the present study, makes possible a useful comparison of results obtained by two different procedures.

The present study, based on recoveries of ammocetes marked by subcutaneous injection of insoluble dyes, was carried out in 1960 to obtain quantitative estimates of population from the ratio of marked to unmarked individuals in samples collected during a chemical treatment. The resulting estimates not only gave an idea as to the actual numbers of ammocetes in the populations, but also provided a valuable check against the dependability of judgments of ammocete abundance based on our surveys. These surveys, conducted by electric-shocking equipment (Braem and Ebel, 1961), have been intended primarily to establish the limits of distribution of sea lamprey ammocetes in streams, but stocks have been classified in such broad terms as extremely abundant, moderately plentiful, or very sparse. These categories, roughly quantitative as they are, may be used to rank streams in the order of need for chemical treatment.

The planning of the experiment included the establishment of distinctive marks, through the use of different colors injected in different locations on the ammocetes' bodies, for each of the several areas into which the streams and tributaries were divided. Subsequent recoveries yielded information on the extent of downstream drift--a point on which we previously lacked accurate information.

All three streams studied are in Michigan's Upper Peninsula: Furnace Creek, Alger County; Snyder Creek, Schoolcraft County; and the Ogontz River, Delta County, (Fig. 1).

Methods

Methods of obtaining and marking individuals were similar for all three streams. Ammocetes were collected with a back-pack shocker, anesthetized in a 75 p.p.m. solution of M.S. 222 (tricaine methane-sulfonate), identified, marked by injection with insoluble dye, and placed in "live cages" to recover before return to the streams. Ammocetes were collected as widely as possible in all sample areas to assure representative coverage of the stream.

The method of marking has been described by Wigley (1952). Four water-insoluble dyes were used: cadmium sulfide (yellow); brilliant orange S.W. (orange)[1]; chrome green (green)[1]; and

[1] Obtained as samples from Mr. John F. LesVeaux, Niagara Chemical Company, Middleport, New York.

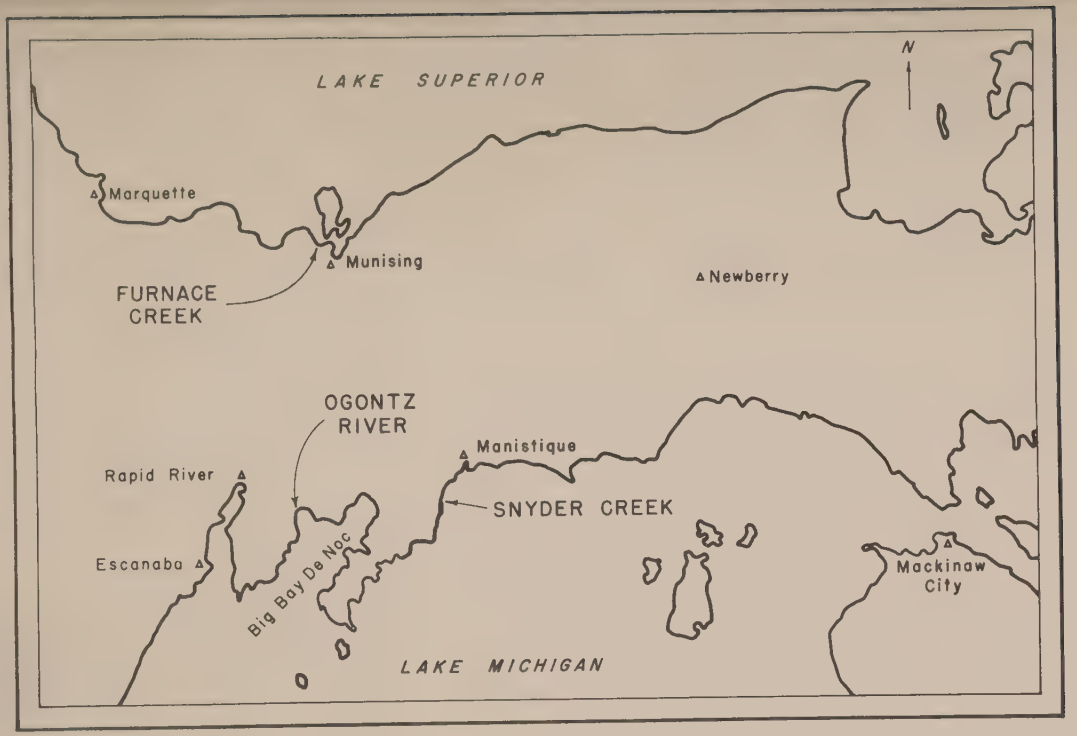

Figure 1.--Map of a portion of the Upper Peninsula of Michigan showing location of the three study streams.

mercuric sulfide (red). The dyes were injected subcutaneously with a 1 c.c. hypodermic syringe and No. 22 needles. A single line, 1/4 to 1/2 inch long, was positioned on one of the following locations (anterior and posterior apply to position in relation to the anus): right anterior; left anterior; right posterior; left posterior; and dorsal in the head area. The combination of four colors and five positions gave 20 identifiable combinations. Actually the greatest number needed in any one stream was eight (Ogontz River). Only ammocetes longer than 1-1/2 inches could be marked.

Larval lampreys recovered rapidly from the anesthetic and marking. Marked animals were held in cages until they had recovered completely and only lively, healthy individuals were returned to the stream. Ammocetes were released in three different ways: in Furnace Creek, they were placed in the upper portion of each area; in Snyder Creek, the marked larvae were artificially redistributed throughout each area; and in the Ogontz River, the marked collections were returned to the location of capture.

An estimate of post-marking mortality was obtained only in the Ogontz River where in late June 150 larvae were marked and placed, with 100 unmarked animals as controls, in a large live box in the lower portion of the main stream. At the conclusion of the experiment 2 months later, 147 of the 150 marked individuals and all of the unmarked ammocetes had survived; mortality then was 2 percent for marked and nil for unmarked ammocetes. The 2-percent figure was used to correct the counts of individuals released in the Ogontz River; no correction was applied to the records for the other two streams. The time between marking and treatment was more than 2 weeks in Furnace Creek and 1-2 days in Snyder Creek.

During the chemical treatment, samples of marked and unmarked ammocetes were collected in riffle fyke nets of 1/2-inch-mesh (extension measure) netting lined with bobbinet in the cod end. The mouth of each net was 52 by 24 inches. Additional samples were obtained by dip netting. Collections were preserved in a 5-percent solution of formalin.

Populations were estimated from the formula $N = \frac{nT}{t}$, where N equals total population, T the total number of individuals marked originally, n the number (marked and unmarked) in the sample, and t the number of marked individuals in the sample. Schaefer (1951) gave an excellent review of the literature on this method of estimating the size of animal populations. We realized the limitations of the method, as described by Schaefer, but

estimates derived were sufficiently accurate to meet the needs of the present study.

Furnace Creek

Furnace Creek, a small tributary to Lake Superior in Alger County, Michigan, originates at Bay Furnace Lake and flows northward about 1/2 mile (2,500 feet) to Lake Superior (Fig. 1). The width varies from 10 to 30 feet and midstream depth is usually between 1 and 3 feet. Three small tributaries above Bay Furnace Lake are not infected with sea lamprey ammocetes (Stauffer and Hansen, 1958). Good lamprey spawning gravel, well interspersed with larval habitat, was present throughout the infected area.

An electromechanical weir and trap operated near the mouth of the stream since 1953 has greatly limited the opportunity for adults to enter the stream and spawn (Erkkila, Smith, and McLain, 1956). Pre-treatment surveys in the spring of 1960 indicated a very small population of sea lamprey larvae and a moderate population of American brook lamprey *(Lampetra lamottei)* ammocetes.

The infected portion of Furnace Creek was divided into six areas, each approximately 400 feet long (Fig. 2). A different mark was assigned for ammocetes in each area. Collections totaling 461 brook lamprey and 17 sea lamprey larvae were obtained by shocking on April 28 and 29. These specimens were marked and returned to the stream in the uppermost portion of the area of capture (Table 1).

Chemical treatment of Furnace Creek was scheduled for May 2, but severe rains and flood forced postponement until May 14. The stream discharge on this date was 35 c.f.s. Six riffle fyke nets were set, one at the lower extremity of each area (Fig. 2). These nets were removed from the water after all swimming activity of the larvae had ceased. Additional samples of dead larvae were collected with dip nets from each section of the stream and from Lake Superior beyond the mouth of the creek.

Collections by both methods totaled 1,458 specimens--493 from the fyke nets and 965 by dip netting. This sample contained 1,400 brook lamprey larvae and 58 sea lamprey ammocetes. The catch included 165 of the 478 marked individuals released.

Records on the locations of recapture disclosed considerable post-marking movement. Individuals from each area were recovered from lower areas, and 6 larval brook lampreys were found in areas upstream from the point of release. Ammocetes are not active swimmers and hence could be expected to appear downstream after the floods and from the drift of dying individuals

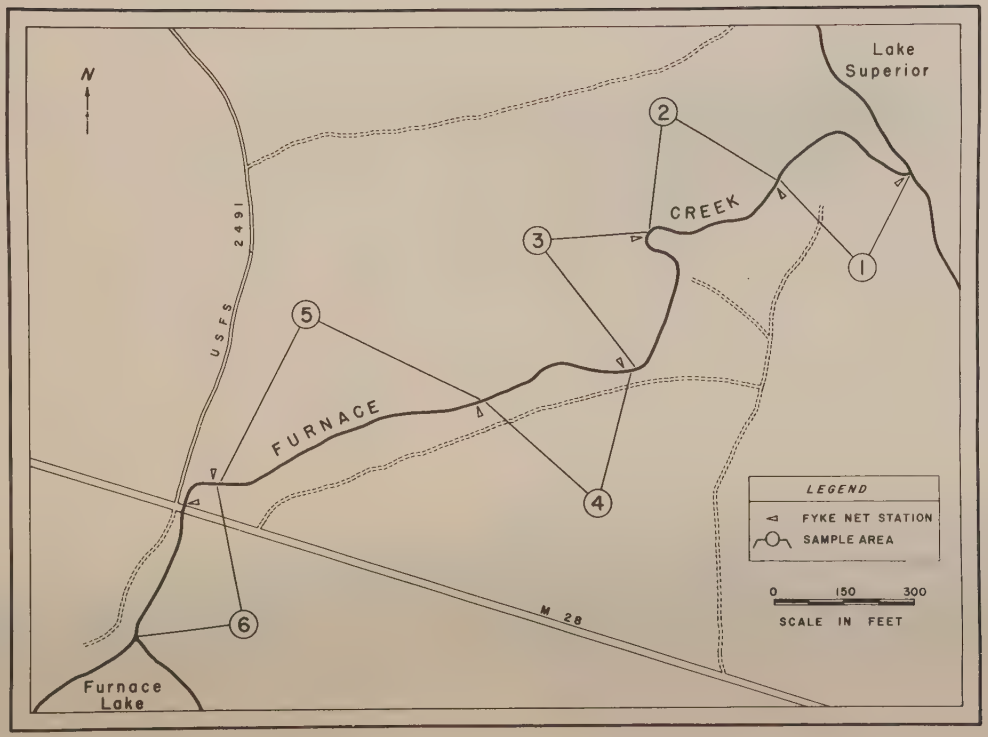

Figure 2.--Map of Furnace Creek showing study areas and fyke net stations.

Table 1.--Numbers of marked ammocetes released and recaptured in Furnace Creek

[See Figure 2 for location of the different areas.

Area of release	Number released	Number and area of recapture							Total recaptured	Percentage recaptured	Total in post-treatment collections
		1	2	3	4	5	6	Lake			
Brook lamprey											
1	91	26	2	0	0	0	0	0	28	30.8	190
2	23	1	4	2	0	0	1	0	8	34.8	78
3	7	0	0	2	0	0	2	0	4	57.0	66
4	107	0	0	1	17	5	20	1	44	41.1	86
5	58	0	0	0	4	5	17	1	27	46.6	103
6	175	0	0	0	0	0	46	5	51	29.1	768
Lake	0	...	...	...	...	...	...	...	...	...	109
Totals	461	27	6	5	21	10	86	7	162	35.1	1,400
Sea lamprey											
1	0	...	...	...	...	...	...	...	...	...	0
2	2	0	1	0	0	0	0	0	1	50.0	5
3	0	...	...	...	...	...	...	...	...	...	2
4	9	0	0	0	0	0	1	0	1	11.1	1
5	3	0	0	0	0	0	1	0	1	33.3	13
6	3	0	0	0	0	0	0	0	0	0.0	31
Lake	0	...	...	...	...	...	...	...	...	...	6
Totals	17	0	1	0	0	0	2	0	3	17.6	58

during treatment. The recovery of ammocetes upstream from point of release was not anticipated. Probably the upstream currents at the edges of the large pools formed during flood permitted some to move into the next upstream area.

The 165 marked individuals recovered included 162 brook lamprey ammocetes (35.1 percent of the number released) and 3 sea lamprey ammocetes (17.6 percent). The considerable amount of movement of the marked animals made it impractical to estimate original populations by area. The estimates are based, therefore, on combined data for the six areas. Recoveries of two species of marked ammocetes made it possible to compare population estimates of each from its own data with those obtained from pooling of both areas and species (Table 2).

Table 2.--Comparison of estimates of ammocete populations in Furnace Creek by individual groups and by pooling groups

Species	Basis of estimates		Difference of estimate	
	Data for individual groups	Pooled data for all groups[1]	Number	Percentage
Brook lamprey	3,984	4,055	71	1.8
Sea lamprey	329	169	-160	-48.6
Totals	4,313	4,224	-89	-2.1

[1] Numbers in the individual categories determined by application of percentage composition of the pooled post-treatment sample of 1,458 individuals to the estimate of 4,224 based on the pooled data.

The estimates for the lamprey groups were 3,984 brook lamprey ammocetes and 329 sea lamprey larvae. The sum of the individual estimates (4,313) was only 89 more than the estimate of 4,224 from the pooled data. Comparison of the preceding estimates for individual species, with those obtained from application of the percentage composition of the post-treatment samples of 1,458 individuals to the estimate of 4,224 from the pooled data, show a similar figure for brook lamprey larvae (a difference of 71 individuals) and a 49-percent discrepancy for sea lamprey larvae.

Both estimates for sea lampreys, 329 and 169, were very low and confirmed the judgments of a small population, based on the pre-treatment surveys with electric shockers.

The sample collected in Lake Superior near the mouth of the creek contained seven (4 percent) of the marked individuals recovered. Application of this percentage to estimates of total population indicated that approximately 170 individuals of both species drifted out of the stream during treatment. The relatively small number of these individuals was reassuring, in that the possibility of significant movement out of the stream into uncontaminated waters and eventual survival had caused concern as to the full effectiveness of treatment. Whether any ammocetes that drifted from Furnace Creek into Lake Superior actually survived is not known.

Snyder Creek

Snyder Creek is a small stream originating in swamps on the Garden Peninsula and flowing into Lake Michigan southwest of Manistique, Michigan (Fig. 1). The width of the stream is 2 to 15 feet and mid-stream depth is 6 inches to 2 feet. A tributary, Deadhorse Creek, which enters the main stream approximately a mile above the mouth, has a flow slightly less than the main branch. Snyder Creek runs through two beaver flowages that contain excellent habitat for sea lampreys.

Distribution surveys prior to the experiment indicated that approximately 2.5 stream miles were inhabited by a very small population of sea lamprey larvae and a large population of American brook lamprey ammocetes. The heaviest concentration of ammocetes was in the lower third of the system. Snyder Creek was divided into three areas: Deadhorse Creek from County Road 435 to the junction with Snyder Creek; Snyder Creek from County Road 435 to the junction with Deadhorse Creek; and the main stream from the junction to the mouth (Fig. 3).

Electric shocking on May 20 and 21, yielded 383 lamprey ammocetes from the three areas. These larvae were identified, marked immediately, allowed to recover, and returned to the stream the next day. The marked individuals were redistributed evenly throughout each area.

The stream was treated on May 22, at a discharge of 21 c.f.s., about double normal low flow. Six fyke net sites, two for each area, were established for recovery of a sample (Fig. 3). In addition, ammocetes were recovered from the entire treated area of the stream with dip nets.

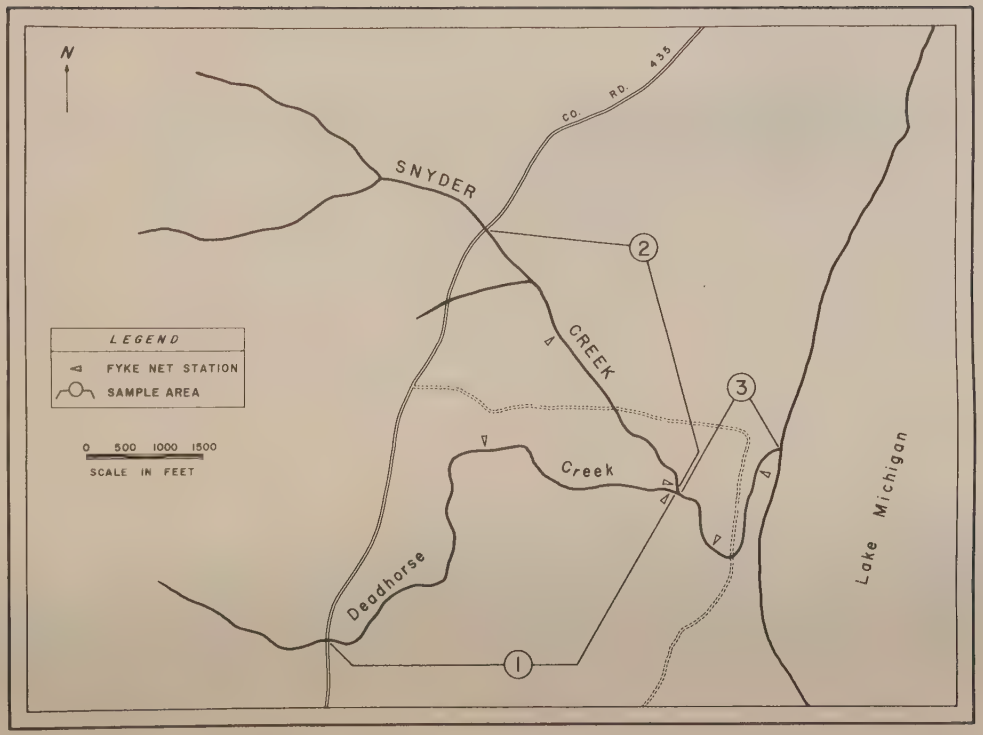

Figure 3.--Map of Snyder Creek showing study areas and fyke net locations.

Collections by both methods totaled 1,605 specimens--435 from the fyke nets and 1,170 by dip netting. The sample contained 1,591 brook lamprey ammocetes and 14 sea lamprey ammocetes. The catch included 20 (5.3 percent) of the 383 marked individuals released.

All marked animals recovered were brook lamprey ammocetes and were recaptured in the areas of release (Table 3). The low rate of flow, physical characteristics of the stream (many slow pools), and the short time between release and collection precluded redistribution of the population.

The recovery of only one kind of marked individual made it impossible to make estimates separately for individual species. Therefore, determinations of numbers in individual categories are based on percentage composition of the post-treatment sample of 1,605 specimens. The lack of movement within the stream did permit estimates by area. Comparison of these estimates with those from pooled data for all areas show a surprisingly close similarity (Table 4). The estimates by individual areas (30,586) and from the pooled data (30,736) differed by only 150 animals (0.5 percent). The number of sea lampreys by area was 269 compared to 277 from pooled data (a difference of 3.0 percent).

Estimates by both methods confirm the judgment, based on the pre-treatment surveys with electric shockers, of a very small population of sea lampreys and a large number of brook lampreys.

The post-treatment collections included no lampreys from the mouth of the creek. The lower part of the stream runs parallel to the shore of Lake Michigan for several hundred feet. The slow rate of flow in this stretch prevented dying individuals from reaching the lake.

Ogontz River

The Ogontz River is a small spring-fed tributary to northern Lake Michigan in Delta County, Michigan (Fig. 1). Stream flow at the mouth is 10 to 50 c.f.s. The river has four large and two small tributaries in a watershed of about 30 square miles. Pre-treatment surveys indicated that approximately 9 miles of the river and its tributaries were infected by a large population of sea lamprey and American brook lamprey ammocetes. An electromechanical weir and trap for adult sea lampreys had been operated near the mouth of the stream in 1958 and 1959. Approximately 500 individuals were captured each year.

Distinctive marks were assigned for ammocetes in eight areas of the stream--three on the main stem and one each on

Table 3.--Numbers of marked ammocetes released and recaptured in Snyder Creek

[See Figure 3 for location of the different areas.]

Area of release	Number released	Number and area of recapture			Total recaptured	Percentage recaptured	Total in post-treatment collections
		1	2	3			
Brook lamprey							
1	111	5	0	0	5	4.5	430
2	104	0	6	0	6	5.8	189
3	162	0	0	9	9	5.6	972
Totals	377	5	6	9	20	5.3	1,591
Sea lamprey							
1	0	...	...	...	...	...	4
2	2	0	0	0	0	0.0	2
3	4	0	0	0	0	0.0	8
Totals	6	0	0	0	0	0.0	14

Table 4.--Comparison of estimates of ammocete populations in Snyder Creek by individual areas and by pooling areas

Stream area	Estimated stock of ammocetes		
	Total	Brook lamprey[1]	Sea lamprey[1]
1	9,635	9,546	89
2	3,311	3,276	35
3	17,640	17,495	145
Total			
Sum for areas	30,586	30,317	269
Pooled data for areas	30,736	30,459	277
Difference			
Number	+150	+142	+8
Percentage	+0.5	+0.5	+3.0

[1] Numbers estimated from species composition of post-treatment sample.

Johnson Creek, East Branch, West Branch, North Branch, and Tributary No. 1 (Fig. 4). These areas were selected to conform partially with the divisions of Hansen and Hayne (1962) and partially with the physical characteristics of the river.

Electrical shocking in the various areas, June 7 to July 1, 1960, produced 4,579 ammocetes--3,212 American brook lampreys and 1,367 sea lampreys. The collection stations were distributed to give coverage in each of the various areas. The ammocetes were anesthetized, identified to species, marked, and returned as near as possible to the location of capture (Table 5).

The Ogontz River was treated chemically on August 31-September 1 at which time stream flow was 28 c.f.s., slightly above low-water stage. The first of seven feeders was started at 4:30 a.m. on August 31, and the chemical reached the mouth of the river 36 hours later. Visual observations during treatment and the post-treatment surveys indicated practically complete extermination of both species of lamprey.

Ammocetes were collected during treatment at 24 stations with riffle fyke nets (Fig. 4) and at 12 locations with dip nets. These collections totaled 12,154 individuals--5,605 sea lampreys and 6,549 brook lampreys (Table 5). The fyke nets accounted for 9,620 specimens and 2,534 were collected by dip netting. The sea lamprey collection contained 576 individuals in the process of

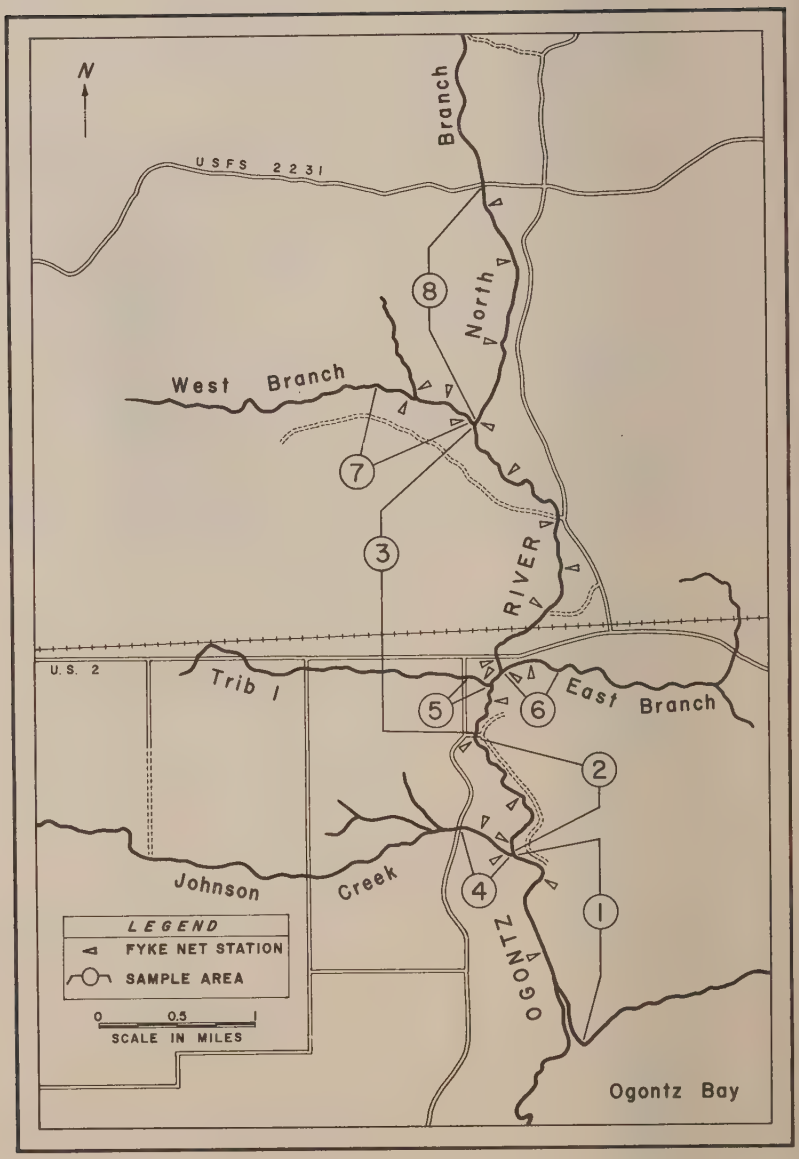

Figure 4.--Map of Ogontz River showing study areas and fyke net locations.

Table 5.--Numbers of marked ammocetes released and recaptured in the Ogontz River

[See Figure 4 for location of the different areas.]

Area of release	Number released[1]	Number and area of recapture								Total recaptured	Percentage recaptured	Total in post-treatment collections
		1	2	3	4	5	6	7	8			
Brook lamprey												
1	852	18	0	0	0	0	0	0	0	18	2.1	867
2	57	0	1	0	0	0	0	0	0	1	1.8	333
3	1,415	0	0	47	0	1	0	0	0	48	3.4	3,526
4	38	0	0	0	4	0	0	0	0	4	10.5	330
5	25	0	0	0	0	3	0	0	0	3	12.0	74
6	7	0	0	0	0	0	1	0	0	1	14.3	95
7	274	0	0	0	0	0	0	13	0	13	4.7	432
8	478	0	0	0	0	0	0	0	36	36	7.5	892
Totals	3,146	18	1	47	4	4	1	13	36	124	3.9	6,549
Sea lamprey												
1	418	3	0	0	0	0	0	0	0	3	0.7	1,346
2	41	1	0	0	0	0	0	0	0	1	2.4	249
3	614	0	1	25	0	0	2	0	0	28	4.6	3,119
4	6	0	0	0	2	0	0	0	0	2	33.3	21
5	41	0	0	0	0	4	0	0	0	4	9.8	88
6	6	0	0	0	0	0	0	0	0	0	0.0	154
7	148	0	0	0	0	0	0	4	0	4	2.7	471
8	65	0	0	0	0	0	0	0	2	2	3.1	157
Totals	1,339	4	1	25	2	4	2	4	2	44	3.3	5,605

[1] The original release number was adjusted on the assumption of 2-percent mortality of marked ammocetes. See section on Methods.

transformation; the brook lamprey sample had 726 transforming specimens. Ammocetes collected in June had given no indication of transformation.

Post-marking movement in the stream was slight, although from 2 to almost 3 months elapsed between the release of marked individuals and chemical treatment. Only five ammocetes were recovered outside the area of marking. Two of them--one from Area 2 recovered in Area 1, and one from Area 3 recovered in Area 2--had moved downstream just below the lower limits of the release areas. The other three individuals were recovered in the mouths of the tributaries where they possibly had moved to avoid the chemical.

The limited numbers of marked animals recaptured in some areas and movement (although not extensive) between areas, made it undesirable to estimate original populations by area. Therefore, the estimates are based on the combined data for the eight areas. Recoveries of both species of marked lampreys made it possible to estimate populations of each from its own data and compare totals with figures obtained from the pooled data for the species (Table 6).

The population estimates for the species individually were 170,570 sea lampreys and 166,154 brook lampreys--a total of 336,724 (Table 6). This sum of the individual estimates was 12,256 more than the estimate of 324,468 from the pooled data. Estimates for individual species, from application of the percentage composition of the post-treatment sample of 12,154 individuals to the figure 324,468 gave values of 174,888 for brook lamprey larvae and 149,580 for sea lampreys. These estimates are, respectively, 5.3 percent above and 12.3 percent below those obtained from data for the individual species. Both methods of estimation confirm the judgment of large populations of the two species, based on the pre-treatment surveys with electric shockers.

The estimates of Hansen and Hayne (1962) of ammocete populations in the Ogontz River were: sea lamprey, 136,800; brook lamprey, 138,700; both species 275,500. These values were respectively 19.8, 16.5, and 18.2 percent below our figures of 170,600 sea lampreys, 166,200 brook lampreys, and 336,700 for the species combined. The disagreements were substantial, but in view of the fact that the estimates were made a year apart and the procedures were altogether different, they cannot be termed excessive.

In contrast to Furnace Creek, the Ogontz River is slow-moving and deep near its mouth. Observations during treatment revealed no movement from the river into the bay. Actually, collection of the post-treatment sample in the lower portion of this area

Table 6.--Comparison of estimates of ammocete populations in Ogontz River by individual groups and by pooling groups

Species	Basis of estimates		Difference of estimate	
	Data for individual groups	Pooled data for all groups[1]	Number	Percentage
Brook lamprey	166,154	174,888	8,734	5.3
Sea lamprey	170,570	149,580	-20,990	-12.3
Totals	336,724	324,468	-12,256	-3.7

[1] Numbers in the individual categories determined by application of percentage composition of the pooled post-treatment sample of 12,154 individuals to the estimate of 324,468 based on the pooled data.

was difficult because of limited numbers of ammocetes. Larvae near the mouth of a stream of this type are not likely to escape into the open lake and thus avoid the action of the chemical.

Acknowledgments

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A PHOTOELECTRIC AMPLIFIER AS A DYE DETECTOR

Wesley J. Ebel

ABSTRACT

A dye detector, based on a modified photoelectric amplifier, has been planned, built, and tested. It was designed to record automatically the time of arrival of fluorescein dye at predetermined points in a stream system. Laboratory tests and stream trials proved the instrument to be efficient. Small changes in color can be detected in turbid or clear water. The unit has been used successfully for timing intervals of more than 17 hours; significant savings of time and manpower have resulted.

Replacement of the clock, included in the original device, with a recording milliammeter increases the efficiency of the unit by continuously recording changes in turbidity. The addition of this component would increase the cost from $75 to approximately $105.

Introduction

Development of new equipment and techniques has contributed greatly to the progress of the sea lamprey *(Petromyzon marinus)* control program of the Great Lakes Laboratory, Bureau of Commercial Fisheries.[1] An important problem in the use of chemicals in lamprey control has been the development of an efficient method of timing water movement. The start of chemical metering must be on a time schedule that allows treated water masses to reach the confluence of tributaries simultaneously. The most effective means of determining the correct time is to introduce fluorescein dye at the application points and record time of arrival at predetermined locations (Applegate, Howell, Moffett, Johnson, and Smith, 1961). This process usually required a large amount of staff time and the extensive use of vehicles. A photoelectric amplifier, modified for use as a dye detector, has been developed to increase the efficiency of this operation.

An instrument for timing water movement had to fulfill the following requirements: simple and durable design to limit mechanical failure; portability, for movement to difficult access

[1] This study is part of a program conducted by the Bureau of Commercial Fisheries under contract with the Great Lakes Fishery Commission.

locations; automatic recording of the arrival time of dyes; sensitivity to small amounts of dye in streams of various colors (turbidities); and, low cost.

Chemical and electrical methods of detection were considered. No suitable chemical system of detection was found since fluorescein is a relatively inert compound that does not enter into chemical reactions easily (Gould, 1955). On the other hand, electrical circuits that can be used to detect variations in water color are readily available. Several of these circuits were investigated and their adaptability studied. All of this equipment contained various light-sensitive elements and had varying degrees of sensitivity to different portions of the light spectrum.

Requirements were best met by modifying a circuit containing a 1P39 phototube (Whitmer, 1960). This phototube has a maximum response between 3,000 and 7,000 angstroms (Bukstein, 1961). Since plate current is linearly related to illumination, it allows the tube to have adequate sensitivity to varying degrees of light intensity and hence to light altered by water color.

Description and Circuitry

The dye detector designed for the sea lamprey program consists of three basic components--a photoelectric amplifier, a waterproof sensing unit, and a power supply (Fig. 1). The power supply is a 12-volt, 72-ampere-hour battery equipped with a 265-volt converter. A 12-volt D.C. electric clock is included in the circuit to permit the recording of time. The complete unit weighs about 20 pounds and can be carried by one man. Cost of all parts and materials is approximately $75.

The amplifier, converter, and clock are all contained in a case constructed of marine plywood. The sensing unit, including a light source to minimize the effects of sunlight and darkness, is contained in a galvanized sheet-metal housing (Fig. 2). This housing is painted black to minimize light reflections. The light in the sensing unit is directed at the phototube at a distance (6 inches) which allows water to circulate freely. The openings to the water space are screened with hardware cloth to prevent activation of the mechanism by floating or suspended objects. One-pint, wide-mouth jars, neoprene tubing and tubing fittings provide waterproof containers for the phototubes, light source and wires. The fragile components are padded with sponge rubber.

The description of the circuit can be followed most easily through reference to the schematic diagram of the detector in Figure 3. The 265-volt A.C. source is coupled to the amplifier

Figure 1.--Dye detector showing sensing unit, photoelectric amplifier, and power supply.

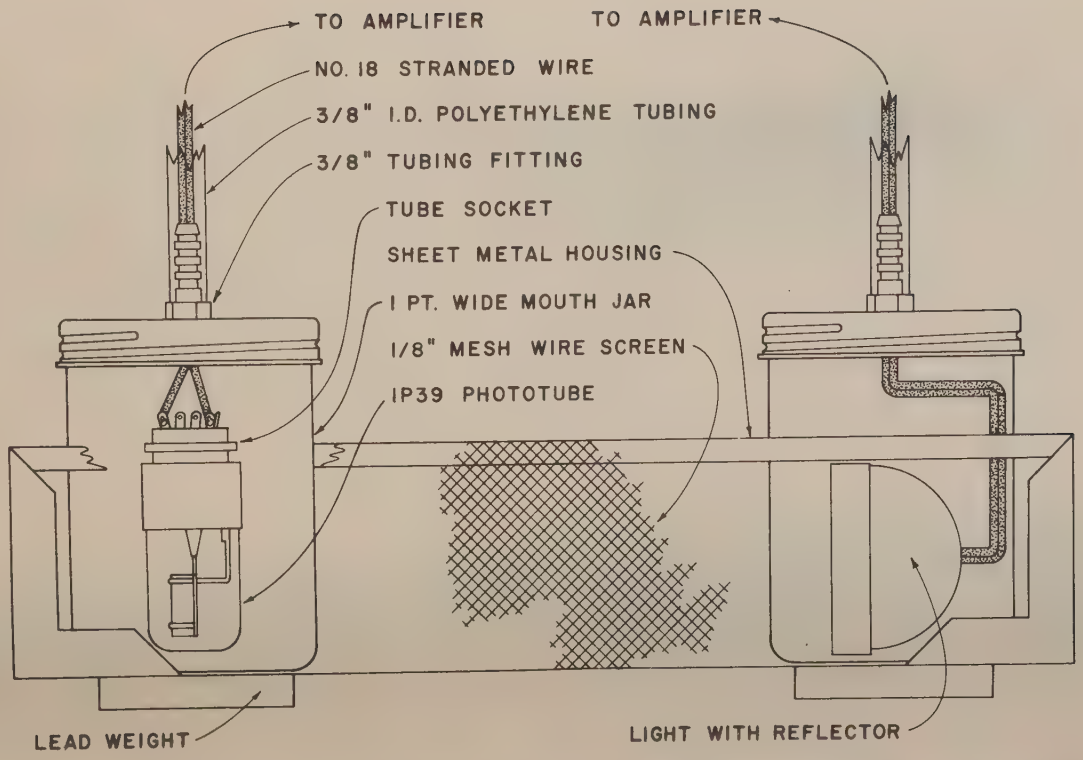

Figure 2.--Diagram showing sensing unit with light source and phototube.

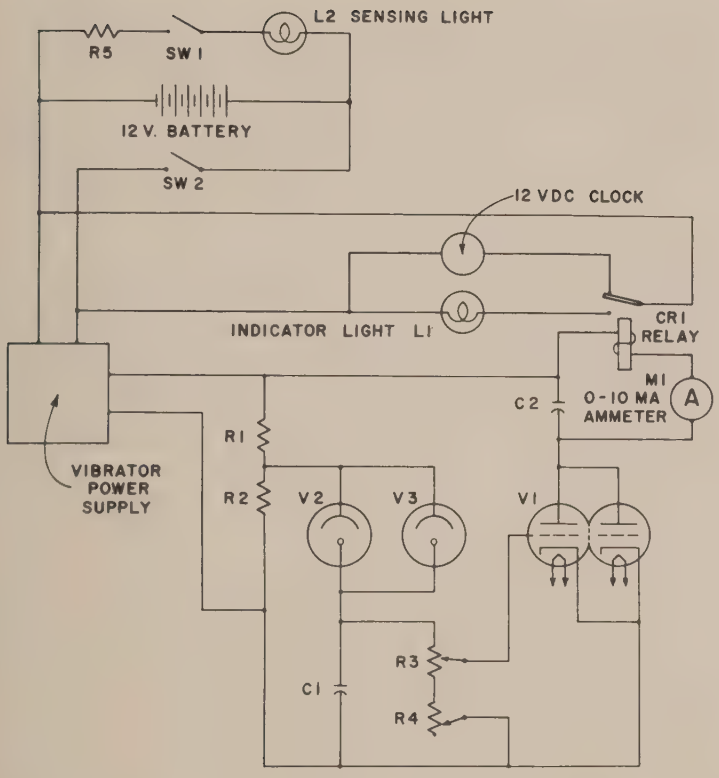

Figure 3.--Schematic diagram of dye detector.

circuit from the vibrator power supply. Cathode voltage at pin 8 of V2 and V3 is obtained from a voltage divider consisting of R1 and R2. When A. C. power is applied, the photoelectric tubes conduct during the half cycle when pin 5 is positive with respect to pin 8--provided the light source is energizing the photocathode. Capacitor C1 and resistor R3 and R4 provide both coupling and time delay. Conduction of V2 and V3 causes C1 to charge. On the

next half cycle, C1 attempts to discharge through R3 and R4. Because the slider arm of R3 is connected to the grid of V1, this tube is biased in accordance with the charge on C1 and the setting of R3 and R4. The polarity of supply voltage applied between plate and cathode of V1 is 180° out of phase with the voltage across V2 and V3, so their conduction periods will occur during opposite half cycles. As long as light energizes the photocathode, the discharge current of C1 through R3 and R4 will be sufficient to keep V1 cut off. When light does not fall on the photocathode, C1 will complete its discharge cycle to the point where V1 can conduct. At this time, current through V1 energizes relay CR1, opening the normally closed contacts and closing the normally open contacts (relay de-energized is considered normal). The current through V1 also charges C2 during this half-cycle conduction period. During the next half cycle when the supply voltage across V1 is such that the tube cannot conduct, C2 discharges through contact relay CR and keeps it energized. The contacts of relay CR1 form a single-pole, double-throw switch. When relay CR1 is closed or activated, indicator light L1 operates and the clock stops, thereby recording the arrival time of the dye.

The sensing light L2 is connected through switch SW1 and resistor R5. R5 reduces current and voltage to the desired level for maximum life of the sensing light. R3, R4, and meter M1 are used to adjust to water color and to control sensitivity. Meter M1 measures current through CR1. Since CR1 activates at 4.6 milliamps and de-energizes at approximately 3.0 milliamps, R3 and R4 can be used to keep amplifier tube V1 operating between 3.0 and 4.6 milliamps output regardless of water turbidity. R3, 10 megohms, provides coarse adjustment and R4, 750K, may be used as fine adjustment. Two phototubes in parallel are used to increase reliability and the 12AT7 is wired in parallel to increase current output.

Because the value selected for C1 is greater than is needed for half-cycle coupling, the time delay will be such that the light to the photocathode must be interrupted for more than one-half cycle before V1 can conduct. This arrangement prevents a momentary cloud of silt from activating the relay. The value which gave satisfactory time delay was 0.025 MFD. A larger value for C1 may be used if more time delay is desired. The closer V1 is adjusted to 4.6 milliamps, the greater the sensitivity of the unit. The greater the sensitivity, the shorter the time delay.

The efficiency and value of the detector can be increased by installing a recording milliammeter to measure continually the flow of current through V1. This record has the advantage of

providing a means of detecting any natural change in water turbidity and provides, not only the arrival time of the dye, but a measure of its duration. It also eliminates the possibility of error from a silt cloud which may last long enough to cause relay CR1 to operate and stop the clock.

Testing and Operation

The detector was tested in the laboratory to determine: correct spacing between light sources and phototubes; optimum milliamp setting; and relative efficiency of one or two phototubes. These points were tested at various turbidity readings from 0 to 400 on a Klett Summerson colorimeter scale and with fluorescein dye concentrations from 0.1 to 3.5 p.p.m. The range of turbidity corresponded with the minimum and maximum values encountered in streams treated in previous years. Water samples of seven different turbidities and with colorimeter readings from 0 to 400 were prepared with tap water.

Two sensing units were constructed, one with a single phototube and one with two phototubes. Both units contained a GE502 bulb with flashlight reflector for the light source. The phototubes and light were tested at several spacings until an optimum distance of 6 inches was determined. A spacing of less than 6 inches gave slightly better results at higher turbidities, but poor results at lower readings. This relation was reversed at a spacing of over 6 inches.

The sensitivity of the units was tested by placing each in the samples of various turbidities and adjusting to five different predetermined milliamp readings on the meter scale. Settings of 3.0, 3.4, 3.8, 4.0, and 4.2 were selected because relay CR1 closes at 4.6 milliamps and reopens at 3.0. (The closing point did not change significantly from 4.6 milliamps in tests at ambient temperatures from 20° to 80° F.) The minimum concentration of dye that would cause operation of the relay was recorded for each of the five settings. The optimum setting derived was 4.0 milliamps. At this setting, 0.4 p.p.m. of dye activated the relay throughout the range of turbidity; the time delay was kept sufficiently large to prevent possible voltage surges from accidentally activating the relay. Comparisons of the two sensing units for relative efficiency throughout the tests disclosed no significant difference.

The dye detector was used successfully during preparations for several treatments of streams with larvicide. These field tests did result in a few failures which can be avoided by heeding the following precautions for efficient operation: the battery

should be fully charged and the milliamp setting should be adjusted after 12 hours of operation; the sensing unit must be waterproof; enough dye should be used to give a concentration at the timing point high enough to activate the unit (a minimum of 0.4 p.p.m.); sensitivity must be checked and necessary adjustments made after 5 minutes of operation (capacitors in circuit must be allowed to stabilize); and the sensing unit should be so placed that neither direct nor reflected sunlight strikes the phototube.

Acknowledgments

Various members of the staff of the Bureau of Commercial Fisheries at Marquette, Michigan, contributed to the development of this instrument. Bernard R. Smith and Richard K. Kanayama advised and assisted in preparation of this manuscript.

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Musky II is one of several research vessels engaged in cooperative studies to learn more about the ecology and fish life of Lake Erie

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Lake Erie or LaKe Eerie?

Changes in Lake Erie already are threatening its potential industrial and recreational usefulness

by Stanford H. Smith

Photos above and below by U. S. Bureau of Fisheries

Scientists lower an instrument that records temperatures at all water depths

Photo by Monroe (Mich.) Evening News

State health authorities have had to stop bathers at many beaches all along Lake Erie

THE AGING PROCESS OF A LAKE is usually so slow and subtle that it frequently goes unnoticed in a lifetime of a man. But Lake Erie is changing rapidly and the progressive changes are threatening its value to the public for many uses.

When lakes are used for the disposal of industrial and human wastes the aging process may be greatly accelerated. Never before, however, has such a dramatic process of premature aging been detected in a lake the size of Lake Erie with its 10,000 square miles of surface area.

Comparative studies have shown that Lake Erie is becoming unsuitable for many traditional uses and an ever-increasing load of wastes entering Lake Erie and the Detroit River have made vast changes in the physical, chemical, and biological characteristics of the lake. As a result, Lake Erie is becoming unsuitable for uses that have been traditional. These changes, formerly noticeable only in the bays and shore areas, have spread throughout the lake, and now are a matter of grave concern to all who have an interest in, or who depend on, this freshwater resource.

A 1951 report of the International Joint Commission on the pollution of boundary waters in the Great Lakes said, "In general, the cumulative effect of uncontrolled waste disposal into these boundary waters seriously reduces the capacity of the waters to perform many beneficial and necessary functions vital to the health, recreation, and economy of the people of the area." A 1953 report of Ohio's pollution survey on Lake Erie declared, "This water is indispensable for the survival and continued growth of the Lake Erie region."

Drastic changes in fish populations

of Lake Erie and the conspicuous insurge of industrial and domestic wastes aroused considerable public concern in the early 1920's. Studies showed that the lower parts of major tributaries and areas in Lake Erie near their mouths were unfavorable for all but the most tolerant fishes.

Interest was again aroused in the late 1940's by further indications of unfavorable conditions in the lake. In the early 1950's, another general research program was established among state, provincial, and Federal agencies of the United States and Canada. This group is currently studying the physical, chemical, and biological characteristics of the lake, and is obtaining information on the nature, degree, and rate of change in the lake through comparisons with results of the earlier studies.

A pollution survey made by the State of Ohio in the early 1950's showed that only 11 of 28 bathing beaches examined were safe for use during the bathing season, and that 9 in the Cleveland area failed by a wide margin to meet accepted standards. The same study showed that water from 14 of 25 tributary streams tested was unacceptable for public use even at the highest degree of water treatment known. It pointed out the need to move domestic water intakes from areas in Lake Erie that were influenced by this highly contaminated inflow.

Much of the bacterial contamination that caused concern in these studies has since been reduced through improved sewage treatment. This treatment has been less effective, however, in removing dissolved chemicals which are steadily building up in the lake.

Lakes age physically, chemically, and biologically. Progress of physical and chemical changes may be inconspicuous, but they are cumulative. A study of four principal Lake Erie tributaries in 1950–51 showed that over 2.6 million tons of silt enter Lake Erie in a year. Gradual filling clogs harbors, resulting in costly dredging operations, and makes the lake shallower and warmer. The use of lake water as a coolant in power plants also contributes to warming. In the early 1950's an estimated 2.8 billion gallons of Lake Erie water were circulated each day through steam-electric generating plants.

An atomic-power station is being built on the lake because of the great requirements for water to cool the reactor. Practically nothing is known of the consequences of increased temperature, or "thermal pollution." Some fish are attracted to warm waters where large numbers may die, and others are known to have very narrow temperature requirements for survival at critical life-history stages. The mean water temperature of Lake Erie has increased approximately 2 degrees since 1918–27. This change has been, in part, related to an accompanying increase in mean annual air temperature. The contributions of other factors to the change are as yet impossible to measure.

Evidences of chemical pollution are clear-cut and impressive. Organic domestic waste of millions of people in communities bordering or near Lake Erie is entering the tributaries and marginal waters of the lake. Inorganic industrial wastes, including toxic substances such as cyanide and phenols, have been reported in analyses of tributary streams and lake waters. In addition, the load of organic industrial waste entering Lake Erie in 1953 was estimated by the U. S. Public Health Service to equal that from a population of about 900,000. Concentrations of most dissolved chemicals have increased during the last 50 years. Calcium, magnesium, sodium, and sulfates show increases ranging from 1 to 10 parts per million. Chlorides showed an increase from 10 p.p.m. in 1930 to about 25 p.p.m. in 1958. Total dissolved solids have increased steadily at an average rate of about 1 p.p.m. per year. There is evidence that the concentrations of nitrogen and phosphorous compounds may have doubled. The effects of overenrichment from accumulating organic materials are indicated clearly by the very low concentrations of dissolved oxygen in the central basin of Lake Erie. During the summer in recent years the area of severe oxygen depletion (less than 1 part per million) has covered approximately one-half the lake. This development has previously been unknown for a body of water the size of Lake Erie.

The biological consequences of increased physical and chemical pollutions of Lake Erie have been spectacular. The mayfly nymph was once the most abundant fish-food organism inhabiting the bottom of Lake Erie. During the past decade these clean-water organisms have decreased to one-tenth of their former numbers—even have been absent in areas where they once thrived. Each spring mayfly nymphs transform into winged adults that once piled up under street lights and store windows in towns along the lake shore—an event that no longer takes place.

Pollution-tolerant worms have increased 4,600 percent, and the aquatic larvae of a small fly that can withstand low-oxygen conditions have increased 533 percent since 1929. The bacterial load at the outlet of the Detroit River increased threefold between 1913 and 1946–48.

The cisco, white-fish, and blue pike that once thrived in the cool, clean water of central Lake Erie, where severe oxygen depletion now occurs, have all but vanished. These species once contributed from 10 million to nearly 50 million pounds each year to the commercial catch, but in recent years have produced only a few thousand pounds.

It is now evident that much of Lake Erie may no longer be a good habitat for the walleye and yellow perch. The less desired but more tolerant species, such as carp, white bass, sheepshead, smelt, gizzard shad, and alewives are more abundant. In addition, reports of fish kills involving all species have become increasingly common in recent years. In fact, recent surveys have shown that at times no fish are present in some areas where they once were abundant.

Indeed, the status of Lake Erie as a useful fresh-water resource has become uncertain, and as impressive as the recorded changes have been, still more dire consequences may arise from accumulations of chemicals that continually enter the lake.

The author is fishery biologist of the Ann Arbor, Michigan Biological Laboratory of the Bureau of Commercial Fisheries

More than 2½ million tons of silt flow into the lake each year from erosion on neglected, gullied land such as this

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TEMPERATURE CORRECTION IN CONDUCTIVITY MEASUREMENTS

by Stanford H. Smith

TEMPERATURE CORRECTION IN CONDUCTIVITY MEASUREMENTS[1]

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U. S. Bureau of Commercial Fisheries, Ann Arbor, Michigan

ABSTRACT

Electrical conductivity has been widely used in freshwater research but usual methods employed by limnologists for converting measurements to conductance at a given temperature have not given uniformly accurate results. The temperature coefficient used to adjust conductivity of natural waters to a given temperature varies depending on the kinds and concentrations of electrolytes, the temperature at the time of measurement, and the temperature to which measurements are being adjusted. The temperature coefficient was found to differ for various lake and stream waters, and showed seasonal changes. High precision can be obtained only by determining temperature coefficients for each water studied. Mean temperature coefficients are given for various temperature ranges that may be used where less precision is required.

INTRODUCTION

The electrical conductivity of natural waters has long been used by limnologists and fishery biologists as a means of estimating the concentrations of certain electrolytes or as a rough measure of dissolved solids, which in turn reflect the relative fertility of a lake or stream. The instrumentation used for salinity determination in oceanographic laboratories gives excellent accuracy. The less sophisticated equipment available to measure conductivity of freshwater lakes and streams in the field requires special consideration for temperature adjustment, particularly where small differences require considerable accuracy. The following discussion gives the background and describes procedures for the finer application of conductometric measurements in limnological research.

Conductivity of natural waters

Conductivity provides a measure of the electrolytic property of water and its solutes. Conductivity measurements of liquids are usually made with instruments that give specific resistance in ohms per cubic centimeter (ohms/cm^3). The reading is converted to specific conductance in micromhos per cubic centimeter (μmhos/cm^3 = 10^6/ohms/cm^3). Since conductance varies with temperature, the temperature at the time of the measurement becomes an essential part of the conductivity record.

The specific conductance of pure water is 0.04 μmhos/cm^3 at 18°C (National Research Council 1929); thus the dissolved electrolytes account for practically all conductivity in natural waters. A small part of the conductivity of water is due to dissolved gases as the conductivity of pure water in equilibrium with the atmosphere is 1 μmho/cm^3 (18°C), chiefly due to the absorption of carbon dioxide (Washburn 1918).

The relationship between the concentration of solutes and conductivity is not linear and varies for different electrolytes. Over the full range of concentration, conductivity increases proportionately with low concentrations, reaches a maximum, then decreases at high concentrations. At the lower concentrations encountered in nearly all unpolluted fresh waters the relationship between concentration and conductivity is nearly linear. Mixtures of electrolytes at low concentrations are approximately additive, but relationships become complex as concentrations increase, and the addition of an electrolyte may even decrease the conductivity (Rosenthal 1950).

Conductivity of electrolytes in water increases with rising temperature and pressure. Since conductivity measurements are usually made after the water has been re-

[1] Frank F. Hooper and Richard O. Anderson assisted in collecting samples used in this study and determined the methyl-orange alkalinities.

moved from the lake, pressure is not a significant source of error, but it must be taken into consideration if *in situ* measurements are made below the surface (Harmon 1958).

Because the conductivity of water increases with temperature, the conductance of different samples cannot be compared unless the measurements are made at the same temperature or adjusted to the conductance at a single temperature. Measurements can be made at one temperature in the laboratory, but more frequently they are made at various temperatures in the field and adjusted to conductance at either 18° or 25°C. The temperature of 18°C is the most commonly used in freshwater research as this value is usually close to the temperature at which readings are taken, and adjustments are subject to less error when the temperature differences are small.

The correction of conductivity measurements at various temperatures to conductivities at a standard temperature is accomplished by applying a temperature coefficient, which reflects the rate of change of conductance per degree of temperature change. This coefficient has been stated frequently as approximately 2% per degree Centigrade ($c = 0.02$) for dilute aqueous solutions. This figure and, more recently, 2.5% ($c = 0.025$) have been commonly used by aquatic biologists to make temperature adjustments with the formula:

$$K_{18} = \frac{1{,}000{,}000}{R_t\,[1 + c\,(t - 18)]} \qquad (1)$$

K_{18} = conductance in micromhos at 18°C.
R_t = resistance in ohms at temperature t.
c = temperature coefficient.
t = temperature at which the measurement was made.

If K_{18} of formula (1) is expressed in terms of resistance, we obtain the following solution for the temperature coefficient c:

$$c = \frac{R_{18} - R_t}{R_t\,(t - 18)} \qquad (2)$$

Equation (2), of course, has no solution for $t = 18$. The value c at this temperature is estimated by the relationship:

$$c_{18} = \frac{R_{17} - R_{19}}{2\,R_{18}} \qquad (3)$$

The temperature coefficient of conductance is, however, like conductance itself, not constant and the factors governing its variation are not simple. The coefficient differs with various electrolytes, and with different concentrations and mixtures of electrolytes, and with temperature. The temperature to which conductivity measurements are adjusted also influences the value of the temperature coefficient, so the coefficients for correction of conductivity to 18°C cannot be used for correction to 25°C.

The temperature coefficients of weak solutions of salts and alkalies vary little with concentration, but change more widely with acids (Tower 1905). The coefficient also depends on the characteristics of the various solutes in the water. In most natural waters, however, acids are absent or weakly represented, and the number of other solutes as well as their concentrations do not vary greatly within a single body. Under such conditions the influence of these factors on the temperature coefficient for a given water may be slight, particularly in the dilute concentration of unpolluted waters.

The influence of temperature of measurements on the temperature coefficient can, however, have a strong effect on the accuracy of the adjustment of results to a standard temperature, particularly where measurements are obtained over a wide temperature range and conductivities vary little. These difficulties were encountered in recent limnological surveys of the Great Lakes initiated in the early 1950's by the U. S. Bureau of Commercial Fisheries. Measurements made in the field over a wide range of temperatures, and even measurements in the laboratory over a narrower temperature range exhibited conspicuous discrepancies despite adjustments by commonly accepted methods. Thus, refinements of

TABLE 1. *Conductivity, total alkalinity and temperature coefficient at 18°C for selected natural waters for which temperature coefficient studies were made*

Stream or lake	Conductivity (μmhos/cm^3 at 18°C)	Total alkalinity (ppm $CaCO_3$)	Temperature coefficient at 18°C
Fleming Creek[1]	442	240	0.0250
Huron River, fall[1]	413	—	0.0250
spring	236	139	0.0257
Whitmore Lake[1]	264	90	0.0251
Lake Michigan	221	113	0.0253
North Lake[2]	127	66	0.0258
Weber Lake[3]	46	19	0.0279

[1] Washtenaw County, Michigan.
[2] Van Buren County, Michigan.
[3] Cheboygan County, Michigan.

temperature correction were essential to make conductivity measurements of Great Lakes waters more accurate and meaningful.

Experiments were accordingly carried out to obtain information on three major points: the variations of the temperature coefficient with temperature in individual waters; extent of differences between waters in these variations; and seasonal changes of temperature coefficient in the same natural water.

METHODS

To determine the extent of variation in the temperature coefficient in different waters, samples were analyzed from four lakes and one stream with conductivities ranging from 46 to 442 μmhos/cm^3; in addition, samples were obtained from the Huron River at both the fall low-water (413 μmhos/cm^3) and the spring high-water (236 μmhos/cm^3) stages (Table 1). The methyl-orange alkalinity of these waters ranged from 19 to 240 ppm as $CaCO_3$.

Measurements were made with an RC-1 bridge and dip-cell electrode manufactured by Industrial Instruments, Inc., of Cedar Grove, New Jersey. Water samples were placed in an ice-water bath and cooled to 4°C. Then the ice was removed and resistance readings were made as the sample warmed to about 32°C. The sample was constantly agitated with a mechanical stirrer as well as with the dip-cell electrode which was completely immersed. Temperatures were taken at each resistance reading with a thermometer that could be read to 0.1°C.

A quadratic regression has been found suitable to describe the relationship between temperature and resistance for dilute solutions at lower temperatures, but a third-degree equation should be used for temperature ranges much in excess of 30°C (Bremner and Thompson 1937). A parabola

$$R_t = a + bt + ct^2$$

R_t = resistance at temperature t
t = temperature
a, b, and c = constants

fitted by least squares to measurements of each water gave a fit that was highly significant (p far smaller than 0.0001). The equations were used, therefore, to calculate resistance values at intervals of 1°C; it was held valid further to extrapolate to 0° and 35°C. All determinations of conductance and temperature coefficients have been based on these computed values of R.

RESULTS

The curves of Figure 1 show for each water and each temperature the temperature coefficient (expressed as percentages) required to adjust an observed conductivity value to conductivity at 18°C. The shape and position of curves of temperature coefficient differed for each sample. Six of the samples fall into a cluster, but Weber Lake stands conspicuously apart. Hooper (1954) reported that Weber Lake had unusually low alkalinity, and suspected that hydrogen sulfide was present in deeper water where the sample for this study was collected.

The forms of the curves for the Huron River samples collected in the fall (low water) and spring (high water) are similar, but the considerable differences in the positions of the curves indicate that a shift in temperature coefficient can result from seasonal changes in chemical characteristics. These samples were taken from the river as it enters the city of Ann Arbor,

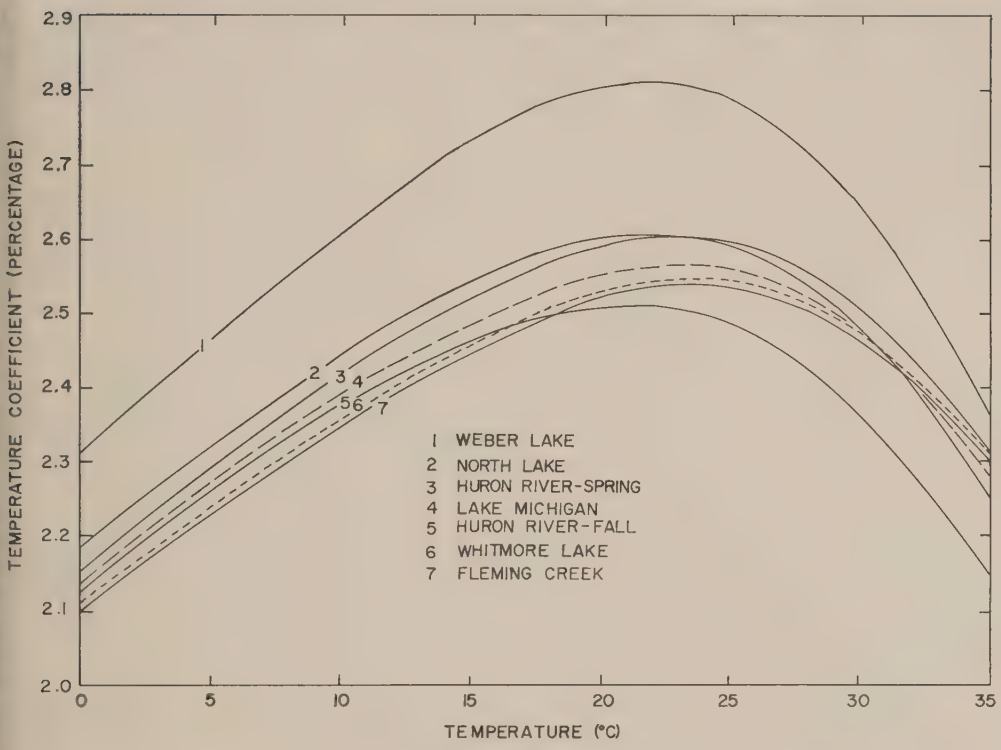

FIG. 1. The relation between temperature and temperature coefficient of conductance for selected waters.

Michigan, above which there is some introduction of industrial and domestic wastes. Since the electrolytes represented would be subject to little change, the differences between temperature coefficients in the samples taken at low and high water in the Huron River probably reflect the influence of differences in dilution.

An explanation for the differences in curves for temperature coefficients of various waters might be found in a detailed study of differences in chemical content. Certainly more research is needed not only to gain a better understanding of the behavior of temperature coefficients, but also to provide greater meaning to the use of conductivity measurements in the description of aquatic conditions.

DISCUSSION

It is obvious that to make precise conductivity measurements it is necessary to determine the variation of the temperature coefficient for the water under study for the temperature range over which measurements are to be made. The data indicated that the error of estimate of conductivity at 18°C rarely reaches 1% when temperature coefficients, expressed to the nearest thousandth, are determined for the water under study. If the coefficient is taken to the nearest ten-thousandth the error seldom reaches 0.1%.

Where it is not possible to determine the variation of the temperature coefficient for the water, or where close precision (up to 10% error) of results is not important, the use of the single coefficient 0.025 would be satisfactory for nearly all natural waters. The error becomes smaller as the temperature at the time of measurement approaches 18°C. If measurements are made over a wide range of temperatures, more

than one coefficient value should be used even though high precision is not required. Results of this study indicate that the following values (from averages, excluding Weber Lake and Huron River in the fall) may be suitable for adjusting conductivity measurements of most natural waters to 18°C.

Temperature (°C)	Temperature coefficient
0–1	0.021
2–4	0.022
5–8	0.023
9–12	0.024
13–19	0.025
20–26	0.026
27–31	0.025
32–33	0.024
34–35	0.023

If, however, water is known to be polluted or to have other unusual chemical characteristics, reasonable precision can be assured only by determining the temperature coefficients for that water over the temperature range within which conductivity measurements are made.

This study has been based entirely on the characteristics of the temperature coefficient for adjustment of conductivity measurements at 18°C. If adjustments are made to other temperatures, the appropriate coefficients must be determined.

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STUDIES OF THE ERYTHROCYTE ANTIGENS OF THE SKIPJACK TUNA (*KATSUWOMUS PELAMIS*)*

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This report is an account of our initial studies of the antigens found on the erythrocytes of approximately one thousand skipjack tuna. These were undertaken in order to find means whereby reproductively isolated stocks of tuna found in the Central Pacific Ocean could be recognized. Numerous authors have shown the utility of such an approach to the problem of distinguishing reproductively isolated posulations within a single species (Cushing, 1952; Cushing and Sprague, 1952, 1953; Ridgway, 1957; Sinderman and Mairs, 1959; Suzuki, 1959; Ridgway and Klontz, 1960; Sprague and Vrooman, 1962).

Two blood group systems called B and C are postulated and several additional blood factors are briefly described.

PROCEDURES

1. *Blood Samples*

Whole blood samples of individual skipjack were obtained by cardiac puncture from fresh fish caught near the following island groups: Hawaii, N. 21°, W. 158°; Marquesas, S. 90°, W. 140°; Tuamotu, S. 16°, W. 146°; and Society Islands, S. 16°, W. 151°. Samples were collected in a modified Alsever's anticoagulant solution containing 16 grams of sodium citrate, 41 grams of dextrose and 14.5 grams sodium chloride in 2 litres of water.

2. *Reagents*

The reagents used were extracts from legume seeds, natural cattle sera and immune rabbit sera. The reagents were kept undiluted in a freezer at −20°C. and diluted just prior to testing. The seed extracts were prepared by soaking 1 gram of ground seeds in 5 ml of modified Alsever's overnight at room temperature. The solution was then centrifuged and the supernatant poured off and stored at −20°C. The supernatant was further diluted 1:6 for testing. Normal cattle sera were usually prepared in dilutions 1:8, 1:16, 1:32. When questionable reactions occurred, adsorption results were used as the final criteria.

3. *Absorptions*

The immune rabbit sera were used in absorbed and unabsorbed form. Double absorptions were performed using 1 volume of centrifuged erythro-

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cytes to 2 volumes of dilute serum. The first absorption was conducted at room temperatures for 10 minutes and the second at approximately 7°C. for 20 minutes. Both the absorbed and unabsorbed sera were used at a final dilution of 1 : 8 for testing.

4. *Blood Typing Technique*

The procedures used to test each sample of tuna blood were as follows: Approximately .05 ml of reagent followed by approximately .025 ml of a freshly washed 10 per cent erythrocyte suspension were drawn into a 1.3–1.5 × 75 mm tube by capillary action. The total fluid involved occupied approximately three-quarters of the volume of the capillary tube. The tube was inverted and imbedded in soft clay contained in a slot on the face of a plastic block. The clay sealed one end of the tube and held it in a near vertical position.

Agglutination readings were made by inverting the blocks and were recorded after 1 to 1-½ hours. A scoring system employing the designations negative (·), trace (tr), and one (1) through four (4) was used. The weakest agglutination which could be observed macroscopically was designated a trace and the strongest clumping was designated a four. In the tables of this report only the summary designations "positive (+)" or "negative (·)" are recorded.

NOMENCLATURE

In order to conform generally to conventional notation, serologically related sets of reactions detected by various reagents are designated as "systems" of blood groups, remembering that the present usage of this term is a special one, since the necessary genetic information relating the reaction to allelic genes is not available.

SEROLOGICAL FINDINGS

1. *The B-System*

The blood factors E, K_1 and K_2 formed a pattern of related reactions we have named the B-system of skipjack. E-positive erythrocytes were recognized by the agglutinating reaction of saline extracts of seed from the legume *Virgilia* sp. The two blood factors K_1 and K_2 were recognized by the agglutinating action of absorbed and unabsorbed immune rabbit serum R-60 (rabbit anti-skipjack). The factors K_1 and K_2 exhibited a subtyping relationship, demonstrable by phenotypic patterns and absorption results.

Table 1 shows the results of absorbing a rabbit anti-skipjack serum (R-60) with erythrocytes from selected individual skipjack. One type of erythrocyte, termed K_1, removed all antibodies from R-60. This type is represented by cells 992, 993 and 997. A second type of erythrocyte, termed K_2, removed some antibodies from R-60, but left antibodies that reacted with cells of type K_1 only. These two cell types therefore appear to be showing relations typical of subtypes.

TABLE 1

Absorption of rabbit anti-skipjack immune serum R-60 by selected cells to demonstrate the pattern of absorptions of the "K" blood factors in the B system

Rabbit anti-skipjack serum R-60

Tested with skipjack RBC	Absorbed by skipjack RBC								
	992	993	997	994	995	1000	939	941	Unabs.
992	·	·	·	+	+	+	+	+	+
993	·	·	·	+	+	+	+	+	+
997	·	·	·	+	+	+	+	+	+
994	·	·	·	·	·	·	·	·	+
995	·	·	·	·	·	·	·	·	+
1000	·	·	·	·	·	·	·	·	+
939	·	·	·	·	·	·	·	·	·
941	·	·	·	·	·	·	·	·	·

A third type of erythrocyte did not agglutinate with unabsorbed (or absorbed) R-60, but nevertheless absorbed antibodies from R-60 that were reactive with K_2 type cells. This type is represented by cells 939 and 941. All cells of this third type that were available for absorption were E positive in contrast to the K_1 and K_2 cells used. It is possible therefore that the E blood factor may cross-react with anti-K_2 and remove it during absorption. However, cells negative for K_1, and K_2 and E blood factors (so far not found in Hawaiian samples, and generally rare) must be studied to confirm this suggestion.

Table 2 lists the number of K_1 and K_2 individuals observed in the patterns formed by testing with anti-K reagents.

TABLE 2

Classification of 1014 skipjack by means of anti-K_1 and anti-K_2 reagents to show the pattern of relationships between K_1 and K_2 bloods

Reagent		Number of individuals tested
anti-K_1	anti-K_2	
+	+	523
·	+	268
·	·	223
Total		1014

Table 3 lists the number of individuals observed in the six patterns formed by the E reaction and the K reactions. While there is an obvious relationship between these sets of reactions, we have no information on the genetic mechanisms that might be responsible for the near reciprocity of the E and K_1 reactions (see table 3). It is evident that much more work needs to be done before the basis for these relationships is ascertained.

2. *The C-System*

Bovine normal sera were previously shown to contain natural heteroagglutinins which react with many but not all tuna erythrocytes (Cushing,

TABLE 3

Classification of 1014 individuals with respect to the six patterns formed by the reaction to reagents E, K_1 and K_2 of the B-system

Reagent			Number of individuals
anti-E	anti-K_1	anti-K_2	
+	+	+	13
+	·	+	125
+	·	·	203
·	+	+	510
·	·	+	143
·	·	·	20
Total			1014

1956). The blood factor recognized by reaction with such sera is designated by us as C_3. In skipjack only two classes of reactions in the C-system were recognized: C_3-positive and C_3-negative. (In other tuna species the regular serological subtyping relationship C_1, C_2, C_3, "–" may be recognized by using additional immune rabbit reagents.) In tests of 1014 individual skipjack, 891 were classed as C_3-positive and 123 as C_3-negative. Table 4 lists the numbers of individuals in these two categories by sample area.

TABLE 4

The relative numbers of C_3-positive and C_3-negative individuals tested in samples collected from four geographic areas during the months September to December in the years 1960 and 1961

Area	Year	Total number	C_3 positive	C_3 negative
Hawaiian Island	1960	108	97 (89.8%)	11 (10.2%)
	1961	234	212 (90.5%)	22 (9.4%)
Marquesas Islands	1960	139	129 (92.8%)	10 (7.2%)
	1961	250	214 (85.6%)	36 (14.4%)
Tuamotu Islands	1960	83	66 (79.5%)	17 (20.5%)
	1961	360	314 (87.2%)	46 (12.8%)
Society Islands	1960	13	... ...	... ...
	1961	170	151 (88.8%)	19 (11.2%)

3. *Other Blood Factors*

Several other blood factors were recognized in skipjack: blood factor A, by the agglutinating action of saline extracts of the soy bean (Glycine max); D, by extracts of the common bean (*Phaseolus vulgaris*); F, by extracts of the bean *Carangana arborescens*. These blood factors are not recognized as part of any known system. The specificities of fluids used to detect them were demonstrably modified by variations in the testing environment, particularly temperature.

POPULATION STUDIES

The occurrence of the blood factors C_3, K_1 and K_2 was tabulated with reference to the frequency of those blood factors among population of skipjack sampled in particular geographic areas.

Table 4 shows the frequency of the C-system phenotypes by sample area for two successive years. The C-system reagents were not useful in separating samples of skipjack from different collection areas.

TABLE 5

The relative numbers of individuals in samples from four geographic areas classified according to the 3 phenotypes observed by testing with anti-K reagents.

Reagent			Sample area			
Phenotype	anti-K_1	anti-K_2	Hawaiian Is.	Marquesas Is.	Tuamotu Is.	Society Is.
K_1	+	+	154 (66%)	83 (33%)	193 (54%)	93 (55%)
K_2	.	+	74 (32%)	67 (27%)	81 (23%)	46 (27%)
"–"	.	.	6 (3%)	100 (40%)	86 (24%)	31 (18%)
Total number tested			234	250	360	170

Table 5 shows the frequency of the K phenotypes by sample area. The relative proportions of the K-phenotypes in the B-system were significantly different ($P < .05$) between some sample areas. The frequencies of these phenotypes in samples from Hawaii were distinct from all other areas, as were those in samples from the Marquesas. Samples from the Tuamotu and Society Islands displayed frequencies distinct from all other areas, but were indistinguishable from each other.

We interpret the data in Table 5 as providing evidence of the occurrence of at least three reproductively isolated populations of skipjack in the areas sampled. In our opinion, at least three reproductively isolated populations have been sampled but we can not exclude, on the basis of the present data, the possibility that some mixture of two populations has occurred in such a way as to yield the proportions observed.

SUMMARY

The results of testing approximately one thousand skipjack bloods from the central Pacific Ocean with several reagents obtained from legume seeds, and normal and immune animal sera, are shown. Significant differences in the frequency of K types (K_1 and K_2) are interpreted as evidence of at least three reproductively isolated populations of skipjack in the areas sampled.

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A RACIAL ANALYSIS OF THE PACIFIC SARDINE (*SARDINOPS CAERULEA*) BASED ON STUDIES OF ERYTHROCYTE ANTIGENS

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This report concerns studies of the erythrocyte antigens of over 2000 Pacific sardines collected off central and southern California and Baja California, Mexico. The objective of this work was to elucidate the relationships between blood factors and the use of these relationships in characterizing reproductively isolated groups of the sardine. Two blood systems, called B and C, are postulated.

Increasing attention has been given recently to the study of the erythrocyte antigens of a variety of teleost species (Suyehiro, 1949), as well as to their use in distinguishing reproductively isolated populations within a single species (Cushing, 1952; Cushing and Sprague, 1952, 1953; Ridgway, 1957; Ridgway and Klontz, 1960).

For example, Ridgway, Cushing, and Durall (1958) reported that groups of sockeye salmon (*Oncorhynchus nerka*) from various breeding grounds could be distinguished. Similarly, Sindermann and Mairs (1959) clearly established the presence of at least two reproductively isolated populations of Atlantic herring (*Clupea harengus*). Hildemann (1956) showed that the inheritance pattern of erythrocyte antigens of the goldfish (*Carassius auratus*) was similar in form to the patterns of other more extensively studied vertebrates such as man, cattle, and chickens (Wiener and Wexler, 1952; Stormont *et al.*, 1951; Briles *et al.*, 1950; Stormont, 1955, 1958).

A review of the literature and an attempt at a synthesis of the biological data on the California sardine is that of Marr (in press). The very detailed analysis of the distribution of eggs and larvae for the years 1939–1941 and 1950–1959 by Ahlstrom (1954, 1959) is also especially pertinent to our study. According to Ahlstrom, the temporal and spatial distribution of spawning is such that reproductive isolation between at least two groups of sardines could easily occur.

Material and Methods

Blood samples. While the biological range of the sardine is from southeastern Alaska to the Gulf of California, our samples collected from Monterey, California to Magdalena Bay in Lower (Baja) California encompass the greater part of the present commercial fisheries of the United States and Mexico.

Blood samples were obtained by cardiac puncture using 18 or 20 gauge needles. The blood was drawn into an isotonic anticoagulant (8 gm. of sodium citrate, 20.5 gm. of dextrose, and 6.5 gm. of sodium chloride, dissolved in 1000 ml. of distilled water and brought to *p*H 7 by use of sodium hydroxide or citric acid if necessary).

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Antisera. Three animal sera are reported on in detail. They are 3573, a cattle antisardine serum; C 5, a chicken antisardine serum; and DA 11, a duck antichicken serum. We believe that the antibody fractions of interest in this serum (DA 11) are normal and not immune serum constituents.

Preparation of blood-typing reagents. In some of the sera, for example 3573, a range of agglutination scores was observed, suggesting that a heterogeneity of antibodies was present. In the cases in which the indicated fractions of antibody could be clarified by absorptions, the resultant fractions were designated as reagents. In those cases, such as serum 3573, where absorptions by the most weakly reactive bloods were sufficient to exhaust the serum of antibodies for the red cells of all sardines, only two categories have been reported, positive or negative, although a variety of positive categories were recognized.

It is our opinion that no utility or logical clarity is added by presenting the variation in such test scores, where absorptions will not fractionate the serum and genetic tools are not available for studying the segregants of various subclasses.

Blood-typing technique. Each blood-typing reagent was diluted to a previously determined optimum, which was usually $\frac{1}{4}$ or $\frac{1}{8}$, and was then heated for 30 min. at 56° C. To each of a series of 10 × 75-ml. tubes was added 2 drops (app. 0.05 ml.) of a given reagent followed by one drop of 2.5 per cent suspension of washed erythrocytes. The tubes were then vigorously shaken and placed in the refrigerator (4° C.) for 3 hours. It should be emphasized that the only reason for placing the tests in the refrigerator was to reduce the tendency of the red cells to lyse at the warm room temperatures, which occasionally reached 36° C. Parallel tests performed at 18° to 26° C. indicated that the cold had little effect on the specificity and degree of agglutination.

Agglutination was recorded at 3 hours and again overnight.

A scoring system employing the designation negative (·), trace (tr), and one (1) through four (4) was used. The weakest agglutination which could be observed macroscopically was designated as a trace and the strongest clumping was designated as a four. In the tables of this report only the summary designations "positive (+++)" or "negative (·)" are recorded.

Absorptions. Absorptions were performed using 1.0 ml. of diluted antisera. The usual procedure was to use 0.5 cc. of washed, packed erythrocytes per absorption, and absorb first for 5 min. at room temperature, and then for 15 min. at 4° C. It is pointed out that few sardines yielded more than 0.5–1.5 ml. of packed erythrocytes.

Results of absorptions were used as the final criterion for designation of a given sample as positive or negative in any case where the direct tests gave doubtful results.

Nomenclature. In order to conform generally to conventional notation, serologically related sets of reactions detected by various reagents are designated as "systems" of blood groups, remembering that the present usage of this term is a special one, since the necessary genetic information relating the reactions to allelic sets of genes is not available. It is assumed, however, that the erythrocyte antigens of sardines are the products of genes, as in other species.

Results

Serological findings. The B system: the pattern of agglutination reactions obtained by testing sardine erythrocytes with three reagents, 3573 (anti-B), C 5 (anti-I), and DA 11 (anti-I), indicated a system of blood groups that we have named the B-system.

TABLES 1 and 2 show the patterns obtained in agglutination tests with anti-B and anti-I reagents.

TABLE 3 shows the results of absorbing anti-I reagents with a group of erythrocytes selected to demonstrate four kinds of cell types.

Red blood cells of types B, BI, and I were recognized by agglutination tests as shown in TABLE 1, and by absorptions as shown in TABLE 3. Erythrocytes

TABLE 1

CLASSIFICATION OF 532 SARDINES WITH RESPECT TO THE B-SYSTEM ANTIBODIES 3573 AND C 5

	5733 (anti-B)	C 5 (anti-I)	N
B	+++		495
BI	+++	+++	19
I		+++	18
			532

TABLE 2

CLASSIFICATION OF 1,291 SARDINES WITH THE B-SYSTEM ANTIBODY 3573 AND DA 11

	573 (anti-B)	DA 11 (anti-I)	N
B	+++	·	1,245
I	·	+++	43
"—"	·	·	3
			1,291

of type Bi were only recognized by their capacity to absorb anti-I fractions from anti-I reagents C 5 and DA 11 as shown in TABLE 3.

All bloods of types B, BI, and Bi absorb anti-B fractions from 3573. Erythrocytes of three fish, designated "—" in TABLE 2, failed to react with either of the reagents, 3573 or DA 11. The bloods of each were used to absorb 3573; one of them (1043) failed to absorb the anti-B fractions of 3573, the other two (1128, 2201) acted to remove the anti-B fractions of this serum. Unfortunately, absorptions were not performed with the sera DA 11 and C 40 using the red cells of 1043 and 1128. Absorptions were performed on DA 11 and C 40 using the blood of 2201, but 2201 did not remove the anti-I activity of these sera.

These observations revealed six kinds of cells. The relationships between cell types as measured by agglutination and absorption results with B system reagents are shown in summary in TABLE 4.

The C system: this system was characterized by the pattern of reactions obtained by testing sardine red blood cells with a variety of sera. The original C reagent was a pool of the "normal" sera of seven big horn sheep (*Ovis canadensis*) furnished by Clyde Stormont.

Some chicken antisardine sera contained C antibodies. A study of the re-

TABLE 3

ABSORPTION EXPERIMENTS WITH SARDINE RED BLOOD CELLS SELECTED TO DEMONSTRATE THE RELATIONSHIP BETWEEN CELL TYPES WITHIN THE B-SYSTEM

Tested with cells		C 5 (anti-I) absorbed by cells				C 5 (anti-I) U*	3573 anti-B U*
Type	Sardine No	110 Bi	105 I	114 BI	100 B		
I	105	-	-	-	+++	+++	-
BI	114	-	-	-	+++	+++	+++
Bi	110	-	-	-	-	-	+++
B	100	-	-	-	-	-	+++

		DA 11 (anti-I) absorbed by cells of						DA 11 (anti-I) U*	C 5 (anti-I) U*	3573 (anti-B) U*
		1992 (Bi)	2014 (I)	2005 (BI)	2007 (Bi)	1993 (B)	2016† (B)			
I	1946	-	-	-	-	+++	+++	+++	+++	-
I	1969	-	-	-	-	+++	+++	+++	+++	-
I	2014	-	-	-	-	+++	+++	+++	+++	-
BI	2005	-	-	-	-	-	-	-	+++	+++
Bi	1992	-	-	-	-	-	-	-	-	+++
Bi	2007	-	-	-	-	-	-	-	-	+++
B	1993	-	-	-	-	-	-	-	-	+++
B†	2016	-	-	-	-	-	-	-	-	+++

* Unabsorbed serum.
† Also C_1-positive.

TABLE 4

A SUMMARY OF THE REACTIONS OF THE SIX RECOGNIZABLE KINDS OF SARDINE BLOOD TYPES IN THE B SYSTEM AS REVEALED BY AGGLUTINATION AND ABSORPTION TESTS WITH ANTI-I AND ANTI-B REAGENTS

Red blood cells from fish of type	Agglutinate in	Absorb anti-I	Agglutinate in	Absorb anti-B
	I reagents		B reagents	
I	yes	yes	no	no
BI	yes*	yes	yes	yes
Bi	no	yes	yes	yes
B	no	no	yes	yes
"—"	no	?	no	yes†
"—"	no	?	no	no‡

* C 5 only.
† Such as cells numbered 1128 and 2201.
‡ Such as cell number 1043.

sults of absorptions of the various antisera containing C antibodies showed that the C system contains at least two C antigens which bear a subtyping relationship (C_1, C_2) to each other. However, all routine testing was performed with anti-C_1 reagents. The data on the frequency of C positive bloods in the next section lists only the frequency of C_1.

Generally sardine red blood cells are either strongly agglutinated by anti-C_1 reagents or they are not agglutinated.

The B and C systems were regarded as independent, since a chi-square "homogeneity" test did not reveal any significant association between the reactions of C and B reagents. Furthermore, and this is perhaps more convincing to the serologist, there was no indication of cross reactions (as exemplified by absorption results) which are so characteristic within systems controlled by multiple alleles.

Several sources of potential misclassification existed; for example, in reagent 3573 both B and C antibodies were found. However, C non B individuals occurred so infrequently that it was not practical to routinely absorb the 3573 reagent to remove the anti-C fractions. However, one such absorption was performed to demonstrate that the B fractions of this serum were not related to the C fractions as regular subtypes. Cell 1755 reacted with anti-I (DA 11), anti-B (3573), and anti-C (CA 8) reagents. This cell, when used to absorb 3573, removed the fraction of 3573 reactive with it (1755), but failed to remove that fraction of 3573 which reacted with a panel of erythrocytes drawn from five B-positive individuals.

In practice, the misclassifications which resulted from a mixture of C and B fractions in the anti-B reagent were probably few. Only two fish were recorded as positive with the anti-I reagent DA 11 and anti-C reagents. They were recorded as being of type I. Two fish were recorded as positive with the anti-I reagent C 5 and anti-C reagents. At the time they were tested the potential problem of their classification was not recognized and no absorptions were performed. It is likely that they were type Bi.

All C_1-positive fish were scored as B-positive as well. The red cells of all C_1-positive fish reacted with the B reagent 3573, since this reagent contained anti-C fractions as shown by absorption. However, since the red cells of only three in 1,291 fish failed to react with anti-I or anti-B reagents, the probability that one of the 164 C_1-positive fish was actually B-negative was very small (about 0.0016).

Population studies. In TABLE 5, data on the frequency of the blood factors I in the B system, and C_1 in the C system are presented for 1,823 sardines.

Eight geographic localities were represented by the samples. Most of the individual samples were taken from a single school of fish, but some of those from San Diego Bay were taken from more than one school.

In TABLE 5 it was possible to separate the samples into two groups by means of the relative proportion of C_1-positive individuals in a given sample. With respect to the frequency of C_1-positive individuals, the samples coded numbers 1–8 have a mean of 13.79 percent and a variance of 8.48. The samples coded numbers 9–15 have a mean of 5.33 and a variance of 0.81. The means and the variances for these two sets of data are significantly different (t-test value equals 7.7 with 9 degrees of freedom).

These data on the geographic distribution of antigen frequencies are interpreted as furnishing evidence that at least two reproductive populations of sardines exist in the areas covered by our sampling.

The data in TABLE 5 were compiled without regard to the ages of the fish. In most samples the ages of the fish, as measured by annular scale rings, varied between 1 and 7 years. The ages of a large number of the fish used in this study have been determined and a short report on the serology and ages of these fish will be presented elsewhere. The fish in the samples coded numbers

TABLE 5

A SUMMARY OF THE RELATIVE NUMBERS OF INDIVIDUALS IN THE CATEGORIES C-POSITIVE AND I-POSITIVE IN SAMPLES FROM VARIOUS GEOGRAPHIC AREAS

Code No.	Geographic area	Season	N	C+	% C+	I+	% I+
1	Monterey, Calif.	59–60	150	18	12.00	2	01.33
2	Morro Bay, Calif.	59–60	147	22	14.97	3	02.04
3	San Pedro, Calif.	59–60	145	16	11.03	3	02.07
4	San Diego, Calif.	59–60	98	15	15.30	3	03.06
5		59–60	110	12	10.90	3	02.73
6		59–60	96	14	14.58	3	03.12
7	Ensenada, Baja Calif., Mexico	59–60	100	12	12.00	4	04.00
8	San Quintin Bay, Baja Calif., Mex.	59–60	41	8	19.51	1	02.44
	Subtotal		887	117		22	
9	San Diego, Calif.	58–59	184	7	03.80	6	03.26
10	San Sebastian Vizcaíno Bay, Mexico 23° N, 115° W	58–59	197	10	05.08	6	03.05
11		59–60	100	5	05.00	4	04.00
12		59–60	99	6	06.06	6	06.06
13		59–60	105	7	06.67	7	06.67
14	Magdalena Bay, Mexico 24°38′ N, 112°10′ W	58–59	151	7	04.64	6	03.97
15		59–60	100	6	06.00	4	04.00
	Subtotal		936	48		39	
	Total		1823	165		61	

4 and 12 are somewhat exceptional, as in each case the entire sample was made up of fish less than one year old.

Discussion

Serology and genetics. The only features of the serological study which were not perfectly straightforward concerned those reactive relationships between erythrocytes and reagents which could only be detected by absorption experiments. As it was, these findings might have been modified if an indirect test or other techniques had been resorted to. At the time, this was not known to be necessary.

Reports on reagents whose reactive properties are only elucidated by means of absorptions are relatively uncommon in the literature, but this is probably due, not to their relative rarity, but to the laboratory economics of using such

troublesome sera. The cattle natural anti-O reagent which detects antigens in blood group systems of man, sheep, swine, and cattle is such a reagent when used on cattle bloods (Sprague, 1958).

It would be desirable to propose a regular system of phenotype-genotype relationships to account for the phenotypic classifications made by means of B system reagents. A variety of attempts to do so have been made, and attempts have been made to test speculations regarding phenotype-genotype relationships of the B system by means of the Hardy-Weinberg formula. To date all such attempts have been unsuccessful. Including the results of absorptions in differentiating up to five phenotypes has not proven successful, possibly owing to the ambiguity of the class "—" or to the sensitivity of the cross reactions which are used to distinguish one phenotype from another.

The C system, by comparison to the B system, is very straightforward. Two C reagents are available which exhibit linear subtyping relationships (Miller, 1958). As stated above, only the relative proportions of C_1 individuals are compared.

Population studies. We believe that the data on the relative proportion of C-positive individuals in our samples provide evidence of at least two reproductively isolated populations.

The data shown in TABLE 5 also provide a basis for some inferences concerning mixing. It is probable that relatively little mixing of any kind occurs in the "southern" sardine population. However, some non-reproductive mixing of adult individuals may occur in the northern range as evidenced by the fact that the variance of the "northern" samples (8.48) is almost 10 times that of the "southern" (0.81) samples.

Seasonal shifts, in the geographic extent of each of these groups, do occur (TABLE 5) and as a consequence so-called "northern" fish have in some seasons been sampled as far south as San Quintin Bay, and "southern" fish have been sampled as far north as San Diego Bay.

Summary

(1) The results of testing the erythrocytes of over two thousand sardines with normal and immune sera which recognize two systems of blood groups called B and C are discussed.

(2) The geographic distribution of antigen frequencies in the C-system are interpreted as indicating the existence of at least two reproductively isolated groups of Pacific sardines.

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SHARK FOR SALE. By William Travis. Pp. 181, pls. 9. George Allen and Unwin Ltd., London, 1961; Rand McNally and Co., Chicago, 1961. $4.95.—This is an exciting and well-written adventure story of commercial shark fishing in the Seychelles. In addition, the story contains a most extraordinary series of observations of interest to the student of shark behavior. I regret that we do not have a parallel scientific account from Travis to bolster our knowledge of the distribution, abundance, and habits of sharks around an oceanic bank. The parts of the story dealing with sharks have the ring of authenticity and the descriptions that Travis has included on the mating behavior of a school of sharks, on the repellent qualities of the heads of dead sharks, on the effects of fishing pressure, and on the responses of sharks to a swimmer, should provide a grist of ideas for the experimentalist.

Travis' shark fishing activities covered two years. Evidently much of his time was spent in the best way to see what goes on in the sea, that is, either adrift or at anchor in a small vessel. He also used SCUBA to investigate reactions of sharks to the various kinds of fishing gear. At least he did this until his experiences highlighted the dangers of the procedure. He sifted lore picked up from Creole fishermen and experimented with gear and methods so that he obtained a wider and better knowledge of shark fishing than he would have obtained from any amount of study ashore. Perhaps then, it is not surprising that he has reported on facets of shark behavior hitherto unknown.

The reader will have to cope with some anecdotes properly falling into the sea-story category. A sea-story, by my definition, is any event happening at sea in apparent violation of the laws of nature or involving creatures or forces not known to exist. But events to be classified as sea-stories are not uncommon and any reasonably complete account of commercial fishing or even of seafaring at speeds of less than 10 knots will have them.

The lengths attributed to the various sharks probably are estimates made without benefit of measuring stick or a notebook—especially a notebook. Writers of popular books are under no obligation to account for their methods in recording data and it may be reasonably presumed that the same forces that work generally on estimates of shark size apply in some degree to those Travis has made. That is, people tend to overestimate the length of any shark larger than the average man and to underestimate the length of any shark smaller than the average man. Furthermore, such estimates, if not immediately noted in writing, tend to slide toward a standard image variously larger or smaller than the original estimate.

The dilemma of the biologist in reviewing this book as a contribution to our knowledge of sharks is illustrated by the report of the capture of two gravid tiger sharks, one 4½ feet long and the other 11 feet long. As far as is known, tiger sharks never become mature until they are about 9 feet long. The existence of a mature tiger shark as small as 4½ feet would be of extraordinary scientific interest, either if it represented a dwarf race of the single cosmopolitan species now postulated, or if it represented a smaller species closely related to the common large tiger shark. Although the tiger shark is one of the most easily recognized of all sharks, errors in identification of sharks are so frequent that I believe that the 4½-foot shark was probably *Hexanchus* or a related shark with six or seven gill slits. Such species are frequently if surprisingly confused with tiger sharks.

The practical aspects of shark fishing are very well handled. Certainly the book has much to offer anyone seriously contemplating shark fishing as a commercial venture or as a research project. The experiences of Travis' shark fishing crew in being nearly incapacitated by damage to hands on their first encounter with large numbers of sharks is a case in point. The solution would have been to supply canvas gloves in sufficient quantity to provide each man with from 1 to 3 pairs for each day of fishing. Hands never become tough enough to deal with very many sharks. *Shark for Sale* is well worth reading by anyone interested in sharks, perhaps with reservations by biologists inter-

ested in specific details of the life histories or in identification of species.—STEWART SPRINGER, *Bureau of Commercial Fisheries, Washington, D. C.*

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pp. 844–845

PELAGIC STAGES OF *ZANCLUS CANESCENS* FROM HAWAII.—Two postlarval moorish idols, *Zanclus canescens* (Linnaeus), were captured by midwater trawl operated by the Bureau of Commercial Fisheries research vessel *Hugh M. Smith* on 9 October 1958. The trawl fished obliquely from the surface to 900 feet between 8 and 11 p.m. The area sampled lay 10 miles off Waianae, Oahu, Hawaii, in water 8,000 feet deep.

The zanclids are 13.4 and 16.0 mm in standard length, and are believed to be the smallest known specimens of their monotypic family. They bear a strong resemblance to acronurus postlarvae of the family Acanthuridae, and it is the purpose of this note to distinguish them from such similar-appearing forms. Only the larger fish has been figured, as the smaller one is essentially identical to it. I wish to thank Tamotsu Nakata of the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, for preparing Fig. 1.

Two distinctive features immediately suggest the familial allocation of the postlarvae. The more conspicuous of these is the elongate third dorsal spine and its filamentous extension. The distance from this spine's base to its filamentous tip is 2.1 times the standard length of the 16.0 mm fish, but cannot be measured in the smaller specimen because of damage. The other distinctive feature is the prominent retrorse preorbital spine above the corner of the mouth. Acanthurid acronuri lack both of these structures.

The preorbital spine merits further discussion in that there has been a controversy regarding the names to be applied to specimens with and without it. In Randall's summary of this dispute (1955, *Nat. Res. Council, Atoll Research Bull.* [*47*]*:169–71*) it was concluded that *Zanclus* was monotypic, *canescens* being the young stage with the spine, and *cornutus* the older stage without it. Randall mentioned the desira-

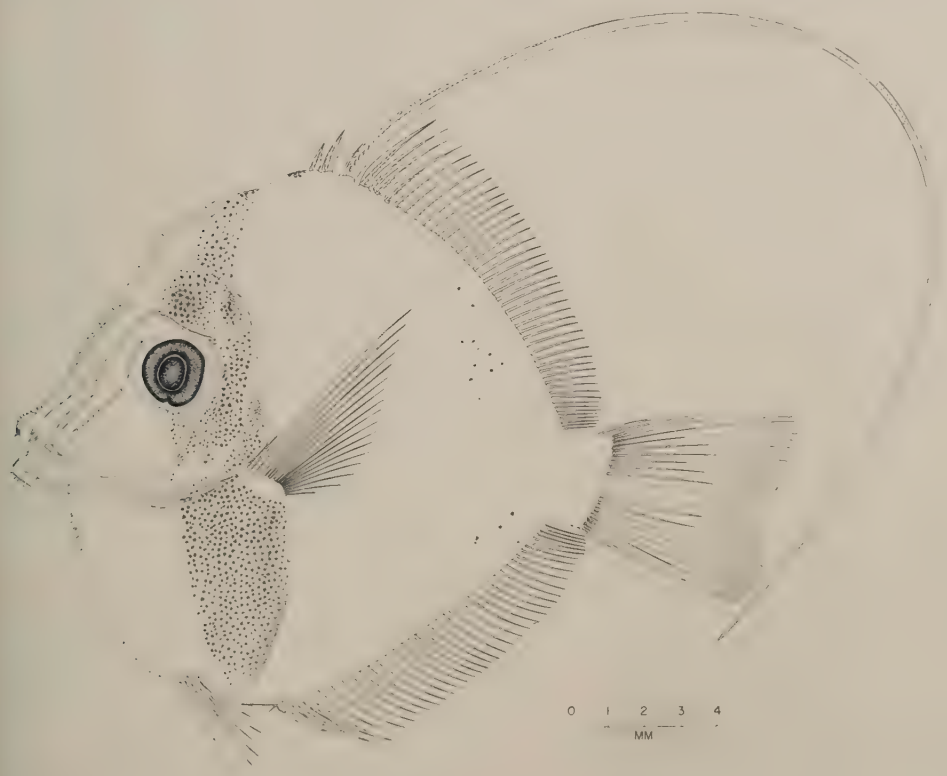

Fig. 1. Postlarval *Zanclus canescens* 16.0 mm standard length. Scales have been omitted and broken fin rays shown as intact.

bility of observing the actual spine loss in a living aquarium specimen.

Everet C. Jones, of the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, maintained a *Zanclus* estimated at 3–3½ inches fork length in an aquarium in late 1961. This fish had the adult color pattern and the preorbital spines when captured. It could not be induced to feed, and died, probably of starvation, after five weeks of captivity. During this interval both preorbital spines disappeared, although it was not determined whether they were shed or resorbed. Regardless of which process took place, their loss constitutes definitive proof of Randall's hypothesis.

The detailed characteristics of my two postlarvae are as follows: D VII, 41; A III, 34 or 35; P 18 or 19; C 8 + 8. Nostrils oval, the anterior about one-fourth the size of the posterior. Teeth erect and conical in both jaws, with 7 on each side above and 7 or 8 on each side below. Opercle and preopercle both smooth posteriorly and weakly serrated ventrally. Head with raised, denticulated bony ridges as follows: curved ridge above eye subcontinuous with straight ridge running to snout, curved ridge before eye subcontinuous with straight ridge running to preorbital spine, two short straight ridges between above straight ridges, two ridges from chin to throat, single ridge on midline of breast. Ascending process of premaxillary with a short crest bearing 4 or 5 teeth. Three short ventroanteriorly directed spines on preorbital above large preorbital spine. Space between snout tip and occiput with several lengthwise rows of denticulations as follows: 4 rows between premaxillary crest and nostrils, 6 rows between nostrils and interorbital region, and 3 rows between interorbital region and occiput.

The dorsal spines are triradiate in cross section, and bear spinules posteriorly and in their lateral concavities. The dorsal soft rays bear weak basal spinules whose number decreases posteriorly. In the 13.4 mm fish, the first 23 dorsal rays bear from 9 to 5 spinules, the next 13 rays have 1 spinule, and the rest lack spinules. Spinulation has decreased in the 16.0 mm specimen, for its first 8 rays bear from 7 to 3 spinules, the next 8 rays have 1 spinule, and the remainder are smooth.

The first anal spine is smooth, triradiate, and equipped with a toothed fan-like structure basally. The second and third anal spines are triradiate and spinigerous. The anal rays resemble the dorsal rays in that they also bear weak spinules. In the 13.4 mm fish the first 13 rays have from 6 to 3 spinules, the next 17 have 1, and the remainder are smooth; in the 16.0 mm fish the first 22 rays have from 12 to 3 spinules, the next 4 have 1 spinule, and the rest lack spinules.

The pelvic spine has denticulate anterior and lateral surfaces, and the outer pelvic ray has a few weak basal spinules. The 5 upper pectoral rays have from 8 to 1 spinules, the number decreasing ventrally. These spinules could not be shown in Fig. 1.

Both specimens are completely scaled except for the branchiostegal membranes and the epidermis over the nasal capsule. Each scale consists of an oval plate lying beneath the integument and parallel to it, and an irregular process arising from the plate's center and at right angles to it. There is great variation in the shape of this process, ranging from a slender needle-like form to a broad fan with 2 to 5 short distal points. The scales are arranged with their long axes running dorsoventrally, and there is a tendency for alignment in rows. Several counts of the scales of the 13.4 mm fish gave from 69 to 72 in a lengthwise series.

Pigmentation of both specimens consists of a broad brown band from the occiput to the belly, a vertical line of dark pigment at the base of the caudal fin, and several dark spots tending to form a bar on the posterior sides. The dorsal filament of the 16.0 mm fish is variably dusky.—Donald W. Strasburg, *United States Department of the Interior, Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii.*

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Some Aspects of the Feeding Behavior of *Remora remora*

Donald W. Strasburg

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Some Aspects of the Feeding Behavior of *Remora remora*

DONALD W. STRASBURG[1]

FOR SEVERAL YEARS the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii, has been interested in holding captive tuna in ponds, and in 1958–59 conducted a series of tests of salt well-water as a medium for these fish. Preliminary experiments took place in a concrete cylinder 8 ft in internal diameter and 5 ft high, in which were confined a variety of reef and semipelagic fish, the latter being important because of our need to anticipate difficulties to be expected with the truly pelagic tunas.

Perhaps the most pelagic of these experimental fish was *Remora remora* (Linnaeus). Two specimens of this species were removed from tiger sharks, *Galeocerdo cuvieri* (Lesueur), on Jan. 16, 1959, and placed in the tank, which already contained several kinds of reef fish. The larger remora measured 170 mm in standard length, the smaller one 76 mm. The fish were fed every day, or every 2 days, and the remoras began eating bread on Jan. 23, continuing to take this and other foods throughout a 1-month observational period. The larger remora succumbed to an eroding infection of the head on Feb. 18, and the smaller one escaped through a drain on Feb. 23.

As soon as they were placed in the tank the remoras exhibited their characteristic attaching behavior. Both fish attached vertically with the head up, the larger fish in a small clearing in the algae coating the tank, the smaller fish to a concrete block placed on the tank's bottom. The larger fish continuously occupied its clearing for the month it lived, and during this period the algae encroached so that the clear space was the size and shape of the remora's disc. The smaller remora's habits were more variable, for it alternated between attaching to the concrete block, swimming freely at the surface, and attaching to the sides of black triggerfish (*Melichthys buniva* (Lacépède)) and parrotfish (*Scarus* sp.).

When first inducing the remoras to feed, food was dropped into the water as near as possible to them. It was soon discovered that they would detach to seize stray bits of food but would immediately reattach after eating, and the question then arose as to what competitive interaction existed between the attaching and feeding acts. A logical second question dealt with their sensory perception, for obviously they would not detach for undetected food. Another variable was the presence of other species, either the host which bore the remora or competitors for food. As these questions arose experiments were undertaken, and records were kept of the kind, quantity, and manner of presentation of food, as well as the behavior of the remoras and the other species. These records form the basis for the present report.

No unusual equipment or methods were employed, but the kinds of food should be listed. Bread was presented in the form of moistened compressed balls varying from ⅛ to ½ inch in diameter, depending on which remora was being fed. Fish consisted of freshly-killed tilapia (*Tilapia mossambica* (Peters)) and swordtails (*Xiphophorus helleri* Heckel) cut into transverse slices or cubes. Shrimp was offered in the form of small cubes cut from commercial frozen shrimp.

FEEDING VERSUS ATTACHING

Prior to examining the relative strength of the feeding and attaching urges in remoras it is necessary to say something about their sensory acuity toward food. Only the larger remora was observed for this, largely because of its single attached position. Food was offered to this animal from two directions: ventrally (toward the tank's center) or laterally (around the periphery of the tank). By starting with food presented

[1] Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii. Manuscript received May 17, 1961.

close to the fish and progressing to offerings spaced increasingly distant it was found that the remora could detect food for at least 48 inches ventrally and 15 inches laterally. It is not known which sense was the most important in this detection, for the more distant offerings were tossed, striking the water with a splash which the fish undoubtedly heard. The water was clear, however, and this, together with the fact that *R. remora* normally feeds selectively on small zooplankters (Strasburg, 1959), may indicate that it could also see ¼-inch pieces of shrimp and bread.

The larger remora was increasingly reluctant to detach and feed when its food was offered from greater distances. Evidence for this is given in Figure 1, which shows the rapid decline in successful feedings with distance (excluding cases where food was approached by another fish). The longest feeding sally was 36 inches, although the fish made short ventures toward food dropped at 42 and 48 inches. The difference in behavior between ventral and lateral food presentations is not understood, but is possibly related to the concomitant binocular and monocular visual situations and the remora's relative ability to evaluate the distance to the food. Both eyes enter into the ventral profile and presumably provide the fish with binocular vision in this direction. All lateral food presentations were from such a direction that they could be seen only by the fish's left eye.

The extent of the larger remora's desire to attach is further manifested in its behavior when simultaneously confronted with two pieces of food. Food was presented ventrally in 25 double feedings at a distance from the remora of 1 to 15 inches. In 17 cases the fish detached, seized one piece of food, and dashed back to reattach to the tank wall, ignoring the second food fragment. In 6 trials the remora did this but immediately after reattaching sallied forth for the second piece of food. Once it ignored both foods and another time it ate both (at a distance of 8 inches) without attaching between feedings. For feedings involving three to eight pieces of food, behavior was much the same, the fish usually venturing out for a single particle, seizing it, returning to the tank wall to reattach, then venturing out again. Toward the end of its confinement it grew rather tame and would eat as many as five food fragments, without reattaching, if they were only a few inches from the attachment site. In general it would seem that the urge to attach is nearly as important as that to feed.

While attached to the concrete block on the tank's bottom, the smaller remora's behavior was much like the larger one's. It ventured after food offered at distances up to 14 inches and usually reattached immediately after seizing it. On three occasions this fish became temporarily free-swimming when food was presented, this occurring when numerous small food particles drifted close by. At such times the remora cruised back and forth through the showers of food at speeds of 0.2–0.4 ft per second, pursuing particles detected as far away as 24 inches. On four other days this fish was unattached throughout the observation period, swimming and feeding at the surface as described above.

The smaller remora spent a total of 11 days attached to triggerfish and 2 days to a parrotfish. The former hosts alternated between circling about the tank at 0.4–0.6 ft per second and wedging themselves into crevices between concrete blocks on the bottom. The remora did not feed when its hosts were in the wedged position. The parrotfish was demersal while it bore the remora, resting quietly on the bottom most of the time but occasionally dashing across the tank, rubbing its side against the bottom in an attempt to dislodge the remora. It appeared that the remora knew this host was a reluctant one, for it was unusually wary of becoming separated. On one occasion the remora had detached and was 2 inches from the parrotfish when the latter flexed its body; the remora, although within an inch of a piece of food, abandoned it to reattach to the host. Another time the remora had loosely attached to the parrotfish while masticating a large lump of bread. Its convulsive chewing and swallowing movements caused it to be displaced an inch or so from its attachment site. The remora's actions apparently disturbed the parrotfish, which tensed and shifted position each time the remora moved. This in turn affected the remora, which ceased chewing and clamped more tightly to the host each time it moved.

While attached to the triggerfish the small remora never ventured more than 6 inches in

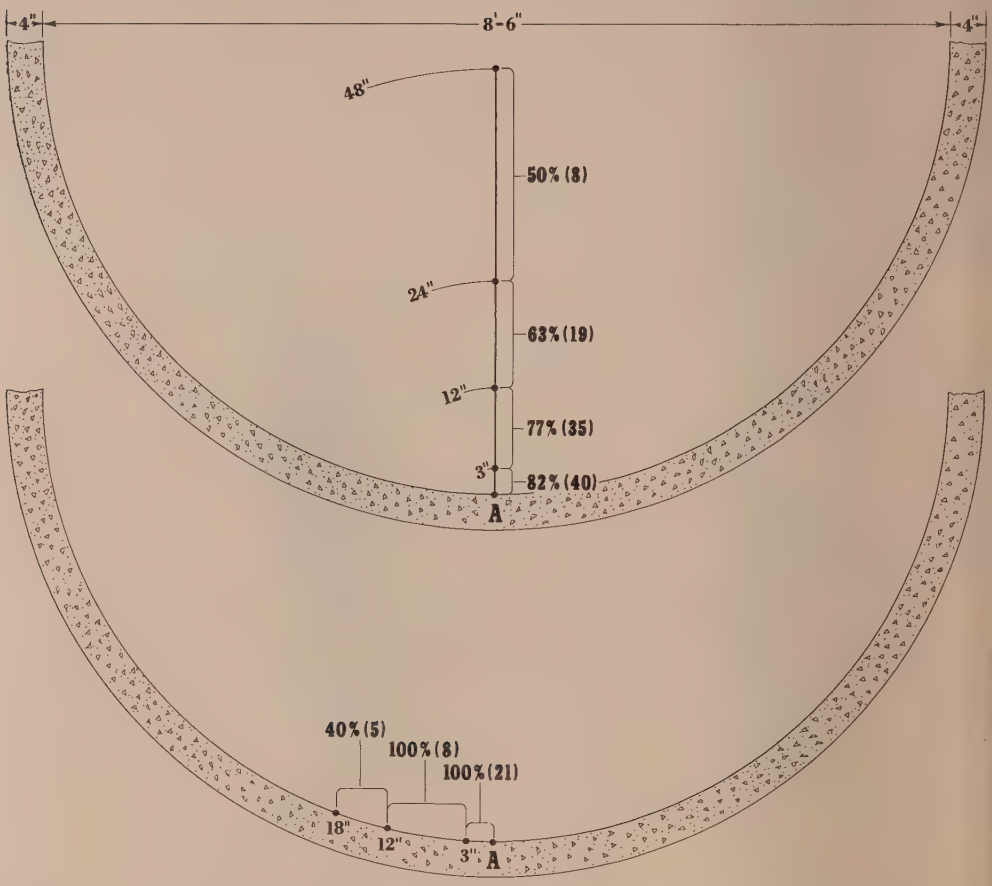

FIG. 1. Percentage occurrence of successful feedings when the larger remora was attached at point *A* and food was offered at successively greater distances. Figures in parentheses represent the total number of food presentations.

pursuit of food, although it reacted to food (by detaching and swimming a short distance) as far away as 12 inches. Of 44 food presentations made within 6 inches, 22 were culminated by the remora's making a successful feeding sally and 20 by an excursion part way to the food. All ventures were immediately followed by reattachment, and when large pieces of food had been seized, by leisurely mastication and swallowing. As noted above, the ingestion of food was often convulsive, resulting in a displacement of the remora by as much as 2 inches along the host's side. It appeared that large items could not be swallowed without loosening the grip on the host, while clamping more firmly to the host often meant losing food from the mouth.

Whenever a food particle fell near the host, the remora undertook a different type of movement in order to feed. The fish slid rapidly over the host's skin, moving forward, backward, or sideways with equal facility, and remaining so close to the host as to appear semi-attached. The extent of contact could not be determined, but probably the disk rim and the dorsal fin actually touched the host. These moves were used in going from the host's sides to the dorsal, anal, and caudal fins, and also in shifting from one side of the host to the other. Ten sliding movements were observed in detail: in six the

remora did not feed, its actions only allowing it to keep the food in view; twice the remora was able to seize food practically touching the host, and twice the remora first slid, then detached and swam to the food. This behavior again emphasizes the strength of the attaching urge in these fish.

RECOGNITION OF ATTACHMENT SITE

As noted earlier, the larger remora was a continuous occupant of a small clearing in the algae coating the tank wall. This was an oval space 3 inches high by 1 inch wide, located 11 inches beneath the surface. The surrounding alga was the diatom *Melosira,* which occurred as a dense growth up to 2 inches in thickness. The remora's disk fitted the clear space remarkably well, the disk being oval and 2¾ inches long by 1 inch wide. After each sally for food the remora returned directly to this site, centering its disk precisely in the clearing, and requiring no shifting of position because of misalignment. Its disk was never seen to overlap the clearing's edge nor were algal filaments ever seen to be drawn into the space beneath the disk. Despite the presence of numerous other alga-free spots in the tank, the larger remora restricted its attaching to this one.

A simple experiment was conducted to see whether this remora could be lured to a new attachment site. Two oval clearings were scraped in the algae, 6 and 12 inches to the left of the original site but identical in size and shape to it. Pieces of food were presented to the remora in such a way that it swam past the new clearings in order to feed. Many times the remora would seize its food within 2 inches of one of the new areas, but in no case could it be induced to attach in them.

The smaller remora was also able to recognize its precise point of attachment, at least when on its triggerfish host. This species, *Melichthys buniva,* is largely jet black in color, but when viewed in certain lights on some occasions it has a brilliant metallic green cast. When the remora detached from a triggerfish the skin to which it had been adhering was a much brighter green than the surrounding area, appearing as a horizontal oval spot on the host's side. When closely scrutinized, this spot was found to contain outlines of the disk laminae and rim, all visible as bright green marks against a black background. Each time the remora detached, it returned precisely to this spot, orienting itself to the spot's shape and position. Judging from preserved specimens, remoras have little or no dorsal vision, and it therefore seems that positioning is accomplished by some other sense. It is suggested that this is tactile, and that the texture of soft attachment surfaces, such as a host's skin, becomes altered through long contact with the disk, enabling the remora to reestablish its position by touch.

EFFECT OF OTHER SPECIES

Among the factors affecting the feeding behavior of remoras are the presence of hosts, potential hosts, competitors, and predators. The host's role as a vehicle is obvious, and as such the rider is carried from place to place, provided with a respiratory flow of water (Strasburg, 1957), and furnished food in the form of ectoparasites (Strasburg, 1959) or scraps. These favorable characteristics are in part offset by the host's tendency to consume any remoras venturing near its mouth, and an inclination to dislodge or injure others by rubbing against hard objects. The beneficial aspects of the host outweigh the negative qualities, however, as is evidenced by a remora's conspicuous urge to attach.

The feeding experiments provided an opportunity to study the relation between an unattached remora and a potential host. This was done only for the smaller remora, because the larger one never attempted to attach to any of the relatively small hosts available to it. The smaller remora was free-swimming or attached to concrete blocks for 8 days following its capture. At this time two large triggerfish were added to the tank, and the remora attached to one or the other of these for the next 11 days, by which time both hosts had died. The next day the remora was attached to the next-largest available host, a parrotfish, the latter making vigorous efforts to rid itself of its adherent by scraping its sides against the bottom. The remora-parrotfish partnership was apparently mutually displeasing, for the remora left this host the same day, and during a 50-minute observation period was seen to make six passes at

other fish. Each pass consisted of the remora's swimming rapidly toward the other fish (*Acanthurus, Chaetodon,* and *Parupeneus*), increasing its speed as it went. The other fish allowed the remora to approach to about a foot, then made a violent turn and fled rapidly. While it is impossible to be certain, it is likely that these maneuvers were attempts to attach. After experiencing several such passes the other fish would no longer let the remora approach them, keeping about 18 inches away from it. This situation prevailed for the remainder of the period of captivity, during which the remora was only once successful in attaching to a fish. This occurred with the parrotfish and lasted for 1 day.

Although the smaller remora was bold when approaching another species, both remoras were very timorous when other species approached them. In 14 feeding experiments it happened that some other tank denizen was attracted to food meant for a remora. Usually the remora had detached and was part way to the food when it realized that another fish was approaching. This resulted in a rapid dash to the attachment site on the part of the remora, and a seizure of the food by the other species (*Parupeneus* and *Abudefduf*). On three occasions the two remoras competed with each other for food. Twice the larger remora abandoned the food to the smaller one, and once it waited until the smaller fish had passed the food before venturing toward it.

SATIATION

An incidental by-product of the feeding experiments was an estimate of the stomach capacity of the two remoras. Although most feedings were not conducted with this in mind, there were a few tests in which the fish were presented with known quantities of food until further offerings were ignored. Where the food was whole fish, volumes were ascertained by water displacement; where balls of bread or blocks of flesh were used, volumes were calculated on the assumption that the balls were spheres and the blocks cubes.

It was found that satiation in remoras resembled that in humans in that the fish not only had favorite foods but also tired of a particular item only to resume eating when a new course was offered. The larger remora became satiated with bread when it had consumed 0.4–2.0 cc; when fed bread until further offerings were ignored and then fed tilapia, satiety occurred with 4.1–4.3 cc; when fed tilapia alone the fish ceased feeding after eating 4.6 cc; and when given shrimp it ate 8.7 cc. A similar but less marked situation was found for the smaller remora. For it, satiety with bread occurred after eating 0.2–0.5 cc; for bread followed by tilapia it happened at 0.7 cc; for fish alone (*Xiphophorus*) it occurred at something less than 1 cc (consumption could not be completely witnessed); and for shrimp at 0.3 cc.

The volume of the 170 mm remora was 56 cc and of the 76 mm fish 4 cc. The largest meal eaten by each was 8.7 and 0.7 cc, respectively, giving a food volume per fish volume ratio of 16–17%. This seems to be typical for a regularly feeding predator, for Nakamura (Ms) found oceanic skipjack (*Katsuwonus pelamis*) consuming about 10% of their own weight at a single feeding, and Hatanaka et al. (1957) found mackerel (*Pneumatophorus japonicus*) consuming 12.5% of their own weight. If *R. remora* were dependent on scraps from its host, one would expect it to be able to ingest large meals and then forego feeding for some time. That it probably eats frequent small meals is suggested by its stomach capacity as well as by the observations of Strasburg (1959), who showed this species to subsist largely on zooplankters. These organisms are captured piecemeal and there is no need for ingesting a single large meal.

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A tag or disk attached to the fish as shown is not harmful. Such tags are used in migration studies of American shad.

TAGGING TELLS FISH SECRETS

JAMES E. SYKES

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RESEARCH biologists in their quest for knowledge about the activities of fish have found that one of the best tools available to them is the technique of fish tagging. By marking or tagging fish as a means of identification and then recapturing them at some later date, scientists have brought many facts to light which could not have been found by other methods. Where do fish go, and how often and how fast do they travel? How many fish are there in certain lakes, ponds, rivers, reservoirs, sounds, and bays? How do they react to man-made changes in their environment? These are but a few of the questions which have been answered through tagging.

Although each species of fish has a fairly definite geographical range, most of them move frequently within this range for reproductive purposes or in search of food. The salmon and the American shad leave the fresh-water streams of the North American coasts after hatching and head for the open sea, remaining there for as long as four or five years, feeding and growing. When capable of reproducing, they return to the stream of origin to produce another generation. Tagging has helped to establish some of this knowledge. Recently the transatlantic trip of a giant bluefin tuna was revealed through tagging. The fish was recaptured in Norway after having been tagged in the Bahamas less than four months earlier. To chart this type of long-range migration a variety of tags is used. One of the most practical is the disk tag. Two plastic disks about the size of a dime are attached high on the back of the fish, one on either side, and secured by a small pin inserted through the flesh.

Among the most useful purposes of tagging is that of estimating the size of fish populations. A forester can count his trees to measure the standing crop, and a dairyman can estimate milk production simply by counting his cows and multiplying the average yield per cow by the number in the herd. The only portion of the fishery biologist's stocks which can be seen, however, is the catch of fish. He therefore puts the fish tag to work for him. A mathematical formula using the numbers of fish tagged and recaptured and the catch of untagged fish yields an estimate of the

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total number of fish in the population, even though many of them are still uncaught and never seen. A nonselective tag, or one which will not increase the chance of recapture by tangling in nets, is used for the purpose of estimating population size. One example is the streamer tag, consisting of a small piece of plastic bearing a number and return information. The plastic is attached to a nylon thread which is inserted through the back of the fish by means of a needle. Jaw tags are also useful for this purpose. This type is most often formed of a stainless steel ring which is clamped through the mandible of the fish with special pliers.

Perhaps the most interesting of all tags, and one which is in keeping with the electronic age, is the recently developed sonic tag used to track local, short-term travels of fish. This is a tiny capsule containing a minute radio-transmitting device. It is attached to the back of a fish which upon being released is followed by biologists in a boat equipped for receiving the radio signal emitted by the tag.

A metal magnetic tag inserted into the body cavity is sometimes used to chart the mass movement of schooling species such as herring. These fish are caught in vast numbers and are reduced to meal and oil in fish factories. For recovery of the tags, electromagnetic devices are installed over conveyor belts in the factories. The tags are detected automatically as the fish pass along the belt.

Marks are sometimes used also to obtain information about the unse activities of fish. The marking proce is especially useful when small fi are involved which would not survi well under the burden of an attach tag. In programs of this nature the fi are either branded, sprayed with lumi ous dye, or have their fins clipped f later identification. When using eith marks or tags, it is essential that th be conspicuous and easily recognizab upon recapture of the fish.

In brief, fish tagging has yield great dividends and will continue do so provided that care is taken choosing the tag which is suitable f the species and the job at hand. In add tion, the recording precisely of information pertinent to each fi tagged and recovered is important.

RESEARCH PROGRAM AT BEAUFORT BIOLOGICAL LABORATORY

By
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The U. S. Biological Laboratory on Pivers Island, Beaufort, N.C. was established by act of Congress in the year 1900. Since that time, research has been carried out almost continuously at this station by the Bureau of Commercial Fisheries according to the needs of the industry and the special qualification of the staff, and by visiting investigators working on problems of interest to the Bureau.

At the present time the staff consists of 47 permanent employees of which 27 are professional scientists. Research is divided into five programs:

(1) The Radiobiological Program, a cooperative investigation between the Bureau of Commercial Fisheries and the Atomic Energy Commission, is currently concerned with the metabolism of radionuclides by marine organisms, the effects of ionizing radiations on marine organisms, and estuarine radioecological studies. The uptake, accumulation, and retention of fission products and certain neutron-induced radionuclides by

phytoplankton, zooplankton, molluscs, crustaceans, and fish are being followed. Marine plants and animals are subjected to X-rays and Cobalt 60 gamma rays. Lethal dosages are determined and the effects on tissues and organ systems, growth, and reproduction are studied. A radio-ecological survey of the Savannah River Estuary is being conducted as part of a cooperative agreement between the Bureau of Commercial Fisheries and the U.S. Public Health Service.

(2) The Atlantic Coast Striped Bass Progam is presently active within North Carolina and Chesapeake Bay fisheries and to a minor extent in cooperative research with the States of Massachusetts and New York. The foremost objectives concern population dynamics and are to determine abundance and mortality rates through tagging and sampling studies; to predict abundance of the highly fluctuating year classes in advance of exploitation; and to evaluate fecundity, or differential in spawning potential between size classes with respect to existing and proposed restrictions on fish size in commercial catches. An attempt is being made through tagging to label separately exploitable stocks within and between coastal areas and to determine biological differences and similarities among the several stocks.

(3) The Menhaden Program research deals primarily with the life history, population structure and dynamics of the Atlantic menhaden stock and is aimed at determining whether variations in yield are related to rates of fishing or result from natural causes. An important phase of the program is concerned with determining the effects of environmental factors on the distribution and abundance of young in estuarine nurseries. Work in the Gulf of Mexico thus far has been confined to establishing the identity and distribution of species supporting the commercial fishery.

(4) The Atlantic Shad Program has been deemphasized during the current year since the major research objectives have been completed. Activities are now confined to collection of catch and effort data on the Connecticut, Hudson, York, and St. Johns River to follow trends in production.

(5) The Blue Crab Program is currently active in tagging blue crabs in the estuaries and off the coasts of North and South Carolina to determine migrations of adult crabs of each sex within and between estuaries. In the Neuse River, North Carolina, population size is being estimated by tagging studies, catch and effort data, and fishing mortality rates. Growth data are being obtained for estimating recruitment and mortality rate of pre-commercial size crabs. In the Newport River, North Carolina, plankton collections are being made at various time cycles and water depths to determine seasonal distribution of the larval forms of the species. In the

St. Johns River, Florida, research is concerned with life history studies, monthly plankton collections to obtain information on distribution of larval forms, a tagging program, and collection of catch and effort data for population and migration studies.

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CLYDE C. TAYLOR (DECEASED).

GROWTH EQUATIONS WITH METABOLIC PARAMETERS

EXTRAIT DU JOURNAL DU CONSEIL INTERNATIONAL
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Growth Equations with Metabolic Parameters

By

the late Clyde C. Taylor
1912–1961

U.S. Bureau of Commercial Fisheries, Biological Laboratory, La Jolla, California

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CLYDE C. TAYLOR, a fishery biologist and biometrician of international reputation, died on 9. November 1961 at La Jolla, California, following surgery to correct a defective heart valve.

He was born in 1912 at Flagstaff, Maine, and took his undergraduate work at Northeastern University, Boston, Massachusetts, and the University of Maine.

In his early professional career he was associated with lobster investigations of the Boothbay Harbor Laboratory of the U.S. Fish and Wildlife Service. In 1947 he became Chief Biologist of the State of Maine Department of Sea and Shore Fisheries. Mr. TAYLOR returned to the employ of the Fish and Wildlife Service in 1950 at Woods Hole, Massachusetts, where he remained until 1959, serving as Assistant Director of the laboratory. He transferred to the Bureau of Commercial Fisheries, Biological Laboratory, La Jolla, California, in the summer of 1959 as leader of the sardine population dynamics programme.

Mr. TAYLOR participated in the advisory meetings of the International Commission of the Northwest Atlantic Fisheries in the United States, Canada, France, and Portugal and served on the committee on research and statistics of that organization. In 1956 he served as a member of the FAO consultant group on classification, terminology and codification at meetings in Biarritz, France.

He was a member of the Biometrics Society, the American Fisheries Society, and a Fellow of the American Institute of Fishery Biologists. His interest in population dynamics is reflected in his numerous publications as "Nature of variability in trawl catches" (1953), "Natural mortality of the Georges Bank haddock" (1958), and "Climatic trends and distribution of marine animals in New England" (1957).

A major interest of Mr. TAYLOR's was in growth studies, resulting in a series of publications: "Cod growth and temperatures" (1958), "Temperature and growth — the Pacific razor clam" (1959), "Temperature, growth and mortality — the Pacific cockle" (1960), all of which appeared in the Journal du Conseil. Only a few days before his death he completed the manuscript

of his paper "Growth equations with metabolic parameters", and it was his expressed wish that it would eventually be published in the Journal.

Clyde TAYLOR's keen mind coupled with his biological and mathematical background enabled him to explore areas of biological hypotheses in original and highly illuminating ways as shown by his analysis of the census trawl data completed at Woods Hole in 1951. He not only demonstrated a tremendous capacity and vital enthusiasm for his own work but also was deeply interested in furthering fishery biology in general, especially with respect to higher professional standards and integrity. His knowledge of mathematics and research planning was willingly put to the service of his colleagues. His role as a research scientist, guiding light, and spur will be missed by all his colleagues.

E. H. Ahlstrom

Patterns of growth in animals take a number of forms, yet there is no evidence that these result from differences in the kinds of physiological processes involved. Rather they appear to be quantitative differences in fundamentally similar processes.

Empirical mathematical functions, including the general polynomial, are available to describe any particular pattern of growth. The need is for simple growth curves with parameters predictably responsive to the changing factors of the physico-chemical and biotic environment. The parameters of an equation based on metabolic considerations, for example, should respond to an environmental factor such as temperature in a manner similar to the known response of metabolism to temperature under laboratory conditions. The search for such equations has, however, been disappointing, and growth functions based on physiological considerations, such as the Bertalanffy (1938) equation or the parabolic equation of PARKER and LARKIN (1959), lack the general applicability that might be expected from their basis of derivation.

In its physical aspect, growth is the net result of the building up and breaking down of cellular material. Raw material for the building up processes (anabolism) must enter the organism through a boundary, a surface or series of surfaces beginning with the epithelial cell membranes and perhaps ending with the transport of material across the surfaces of subcellular bodies such as the microsomes and mitochondria where metabolic processes continue (LINDBERG and ERNSTER, 1954). The breaking down of material (katabolism) occurs within a mass contained by a surface. The removal of katabolic products including heat energy again occurs across surfaces.

These processes of income and outgo may be expressed as equations of continuity having the general form: —

$$dX/dt = U - V \tag{1}$$

Equation (1) states that the net change in X per unit time is the surplus of U added per unit time over that of V removed per unit time.

Thus BERTALANFFY (1938) derived a growth equation from the continuity relation: —

$$dw/dt = Hs - kw \tag{2}$$

which states that the increase in weight per unit time, dw/dt, is equal to the weight synthesized per unit surface area, H, times the total surface area, s, minus the destruction per unit weight, k, times the total weight, w.

BERTALANFFY assumed that the area of surfaces involved in anabolic processes is proportional to a linear dimension squared and that the weight related to katabolic processes is proportional to a linear dimension cubed: —

$$s = pl^2 \tag{3}$$

and

$$w = ql^3 \tag{4}$$

where l is length and p and q are constants of proportionality. Making appropriate substitutions, equation (2) is expressed in terms of length as: —

$$dl/dt = E - Kl \tag{5}$$

where $E = Hp/3q$ and $K = k/3$.

Integration of equation (5) leads to the Bertalanffy growth equation: —

$$l_t = E/K - (E/K - l_0)\, e^{-Kt} \tag{6}$$

As t becomes large, l_t approaches E/K as the limit, L_∞, and letting $l_0 = 0$ when $t = t_0$, equation (6) is usually written: —

$$l_t = L_\infty\, (1 - e^{-K(t-t_0)}) \tag{7}$$

BERTALANFFY ascribes equation (2) to PÜTTER (1920). PÜTTER developed equation (2) to the form: —

$$\lambda = L\, (1 - ae^{-Ct/L}) \tag{8}$$

where λ is length, a and C are constants, and L is the asymptotic length. Thus equation (8) differs from (7) in notation only. PÜTTER (1920) appears to have appreciated some of the more interesting properties of equation (8), for he notes that animals at higher temperatures should show more rapid growth but a smaller final size, and that animals at lower temperatures should grow larger.

Generalization of the Differential Growth Equation

In fish it is known that weight seldom varies exactly in proportion to a linear dimension cubed, although deviations from the cube usually are not large. Values of the exponent have been reported over the range from about 1·4 to 4·0 (BROWN, 1957; RICKER, 1958). Nor does available evidence, such as variations in gill area (FRY, 1957, Table II), and variations in intestinal area as indicated by variations in intestine length (HARDER, 1958) lead to any confidence that a linear dimension squared is a reliable index of the surfaces actually related to anabolic processes; these surfaces are, in part at least, undetermined or indeterminate.

More generally, let: —

$$s = pl^a \tag{9}$$

and

$$w = ql^b \tag{10}$$

where a is the exponent relating length to the surfaces involved in anabolic processes and b is the exponent relating length to "effective metabolic weight" (see Discussion).

From equation (10): —

$$dw/dt = bql^{(b-1)}dl/dt \qquad (11)$$

Substituting values of s, w, and dw/dt from equations (9), (10), and (11) respectively in equation (2): —

$$dl/dt = El^{(a-b+1)} - Kl \qquad (12)$$

where $E = Hp/bq$ and $K = k/b$.

BERTALANFFY (1957) generalizes equation (2) by writing (in the notation of this paper): —

$$dw/dt = Hw^m - kw.$$

Integration leads to equations in weight or length essentially similar to equation (14) below (BERTALANFFY, 1957; HOLT, 1958; CHAPMAN, 1961).

I am indebted to Sidney HOLT (personal communication) for pointing out that the growth equations I deduce from equation (12) by consideration of the results of experiments in animal metabolism and possible limiting values of the quantity $(b-a)$ have already been discussed from a mathematical and empirical point of view by RICHARDS (1959).

Derivation of Growth Equations with Metabolic Parameters

From equation (12) it is possible to derive several growth equations in terms of metabolic parameters which express some commonly encountered patterns of growth. The Bertalanffy equation (7) and the Ford-Walford regression (FORD, 1933; WALFORD, 1946) are seen to be special cases of more general, and perhaps more generally applicable, growth equations. The various growth equations result from quantitative differences assumed to hold among the parameters a, b, E, and K. The validity of these assumptions is examined under Discussion.

Case 1. $a \neq b$. Integration of equation (12)

Factoring, separating variables, integrating, and evaluating the constant of integration at $t = 0$, equation (12) becomes: —

$$l_t^{(b-a)} = E/K - (E/K - l_0^{(b-a)})\, e^{-K(b-a)t} \qquad (13)$$

Case 1 a. $a < b$. General form of the Bertalanffy equation and Ford-Walford

Under this condition when t becomes large $l_t^{(b-a)}$ approaches E/K as the limit, $L_\infty^{(b-a)}$, and letting $l_0 = 0$ when $t = t_0$, equation (13) may be written

$$l_t^{(b-a)} = L_\infty^{(b-a)}\,(1 - e^{-K(b-a)\,(t-t_0)}) \qquad (14)$$

Equation (13), when $a < b$, and equation (14) are general forms of the Bertalanffy equation, corresponding to equations (6) and (7) respectively.

From equation (14) the relation: —

$$l_{t+1}^{(b-a)} = ml_t^{(b-a)} + i \qquad (15)$$

is readily derived, where m is the slope and i, the intercept of a straight line. Equation (15) is a generalization of the Ford-Walford regression: —

$$l_{t+1} = ml_t + i \tag{16}$$

It should be noted that m and i in equation (15) are related to L_∞, K, a, and b through the relations: —

$$m = e^{-K(b-a)} \tag{17}$$

$$i = L_\infty{}^{(b-a)}\,(1 - e^{-K(b-a)}) \tag{18}$$

The time required for an organism to attain 95% of its ultimate length has been proposed as a measure of lifespan and designated $A_{0.95}$ (TAYLOR, 1958a). For equation (7): —

$$A_{0\cdot95} = \frac{2\cdot996}{K} + t_0 \tag{19}$$

For equation (14) the relation is similar: —

$$A_{0.95} = \frac{2\cdot996}{K'} + t_0 \tag{20}$$

where $K' = K(b–a)$.

Expanding both sides of equation (14) to the $1/(b–a)$ power, an equation in l_t is obtained. Taking the second derivative of the expansion, there is a factor which, when equated to zero, shows that the untransformed lengths, l_t, have a point of inflection at time t_i: —

$$t_i = t_0 - \frac{\log_e(b-a)}{K} \times (b-a < 1) \tag{21}$$

Equations (14) and (15) are, then, applicable to growth data showing a point of inflection in the plot of l_t on t. When the data show an inflection $(b-a)$ will be less than 1.

Case 1 a (1). $b-a = 1$. Bertalanffy equation and Ford-Walford regression

When $b-a = 1$, one sees by inspection that equations (14) and (15) reduce to the Bertalanffy equation (7) and the Ford-Walford regression equation (16) respectively. The particular values of a and b used by BERTALANFFY were 2 and 3 but case 1 a (1) is more general than that. The reduction of the general Bertalanffy equation (14) to equation (7) is effected when the ratio a/b corresponds to a term in the series: —

$$\tfrac{1}{2}, \tfrac{2}{3}, \tfrac{3}{4}, \ldots. \; n/(n+1)$$

or, more generally, to the term: —

$$y/(y+1)$$

where y may take continuous values (see Discussion).

It will also be noted, of course, that equations (16) and (19) reduce to their corresponding forms for the Bertalanffy equation and that as $(b-a)$ approaches 1, the point of inflection approaches t_0 (equation (21)).

Case 1 b. $a > b$. Logistic growth

The generalization in case 1 specifies only that a does not equal b. It is unlikely that a is ever greater than b. This condition is examined because it shows that general equation (13) is closely related to the logistic equation and perhaps ought to supplant entirely the latter.

When $a > b$ the exponent $(b-a)$ in equation (13) is negative so that the equation may be written: —

$$l_t^{(a-b)} = \frac{K/E}{1 + (K/El_0^{(a-b)} - 1)\, e^{K(a-b)t}} \tag{22}$$

This is a generalized logistic equation with upper asymptote equal to K/E when t approaches infinity and lower asymptote at zero when t approaches negative infinity. The properties of the logistic equation have been discussed by WINSOR (1932).

Case 2. $a = b$. Exponential growth

If $a = b$ equation (12) reduces to: —

$$dl/dt = l(E - K) \tag{23}$$

Integrating (23) the equation for exponential growth is obtained: —

$$l_t = l_0 e^{(E-K)t} \tag{24}$$

RICKER (1944) has used the exponential equation to describe growth in weight and BRODY (1945) has used it to describe the accelerating phase of growth.

Case 3. $a < b$. $K = 0$. Parabolic growth

There are some examples of fish growth which appear to result from a purely additive process. Exponential growth is such, proceeding at a rate proportional to the length at any time. PARKER and LARKIN (1959) consider some examples of additive growth and develop a "parabolic growth equation" to describe it.

Letting $K = 0$ in equation (12): —

$$dl/dt = El^{(a-b+1)} \tag{25}$$

Separating variables and integrating: —

$$l_t^{(b-a)} = (b-a)Et + l_0^{b-a} \tag{26}$$

Thus for this kind of growth, there is a transformation of lengths at time t such that the plot of $l_t^{(b-a)}$ on t is linear with slope $(b-a)\,E$ and intercept l_0^{b-a}.

Letting $(b-a)E = \alpha$ and $(b-a) = z$, equation (26) may be written: —

$$l_{t+1}^{z} = l_t^{z} + \alpha \tag{27}$$

This is precisely the result which PARKER and LARKIN (1959) derive from the relation: —

$$dM/dt = kw^{x} \tag{28}$$

Equation (28) is identical in form to equation (25) (see Discussion).

Writing equation (26) as: —

$$l_t^z = \alpha\, t + l_0{}^{b-a} \tag{29}$$

the latter appears to have analytic advantages over equation (27) because it is expressed in terms of the independent and explicit variable t.

Comparative Results in Applying Equations to Fish Growth Data

Figure 1 shows growth data (GRAINGER, 1953, Table V) for the Arctic char (*Salvelinus alpinus*) plotted as l_{t+1} on l_t (equation 16). The regression equation is: —

$$l_{t+1} = 0{\cdot}9712\, l_t + 4{\cdot}0 \tag{30}$$

From equation (30) one estimates $L_\infty = 138{\cdot}9$ cm, $K = 0{\cdot}0292$ and $A_{0.95} = 105$ years. The estimates of L_∞ and $A_{0.95}$ are obviously absurd because the oldest fish in the sample had an average size of only 68·6 cm at 24 years.

Figure 2 shows the same data plotted by equation (15) with a trial value of $(b-a)$ of 0·3: —

$$l_{t+1}^{0.3} = 0{\cdot}8895\, l_t^{0.3} + 0{\cdot}44 \tag{31}$$

From equation (31) parameters are estimated as follows: $L_\infty = 79{\cdot}4$ cm, $K' = 0{\cdot}1274$, and $A_{0.95} = 25{\cdot}3$ years. The regression is now more nearly linear (Figure 2) and the parameters are in much better agreement with observation.

By equation (21) an inflection in growth is indicated at time: —

$$t_i = \frac{-\log_e(0{\cdot}3) - 1{\cdot}8}{0{\cdot}1274}$$
$$= 7{\cdot}6 \text{ years}$$

The inflection may be seen in Figure 3.

Figure 4 shows growth data (HASLER, 1938) for the rainbow trout (*Salmo gairdneri*) at Crater Lake, Oregon, plotted as l_{t+1} on l_t. The regression line is: —

$$l_{t+1} = 0{\cdot}9620\, l_t + 4{\cdot}11 \tag{32}$$

From equation (32) one estimates $L_\infty = 108{\cdot}2$ cm, $K = 0{\cdot}0387$, and $A_{0.95} = 77{\cdot}4$ years. The oldest fish observed was 5 years old with an average length of 17·6 cm.

Figure 5 shows the same data plotted as: —

$$l_{t+1}^{0.4} = 0{\cdot}6158\, l_t^{0.4} + 1{\cdot}318 \tag{33}$$

Again $(b-a) = 0{\cdot}4$ is a trial value. L_∞ is estimated as 21·8 cm, K' as 0·4848, and $A_{0.95}$ as 6 years.

Figure 6 shows growth data (PROBST and COOPER, 1954) for the lake sturgeon (*Acipenser fulvescens*). The regression line is: —

$$l_{t+1} = 0{\cdot}9218\, l_t + 5{\cdot}2 \tag{34}$$

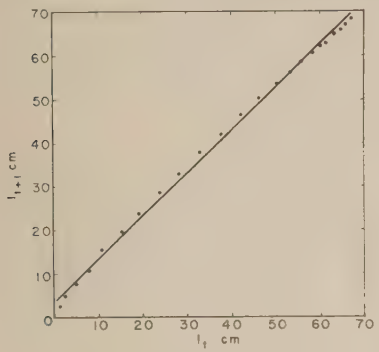

Figure 1. Plot of $l_t^{0\cdot3}{}_{+1}$ on $l_t^{0\cdot3}$ for *Salvelinus alpinus*. (Data from GRAINGER, 1953.)

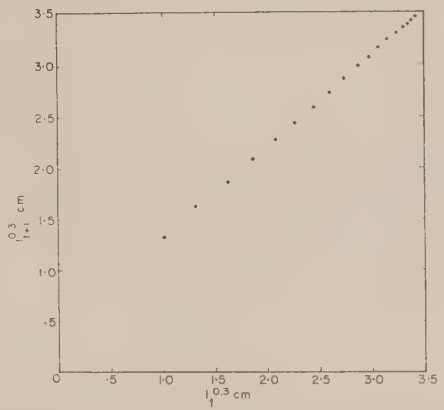

Figure 2. Plot of $l_t^{0\cdot3}{}_{+1}$ on $l_t^{0\cdot3}$ for *Salvelinus alpinus*. (Data from GRAINGER, 1953, Table V.)

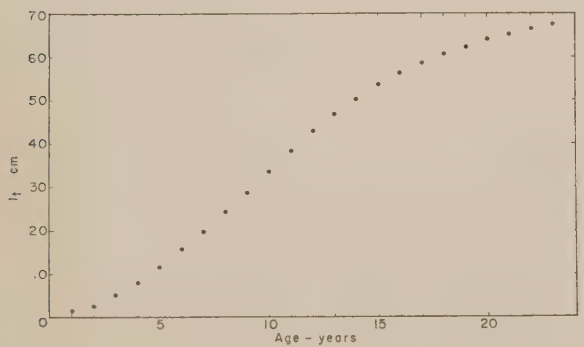

Figure 3. Plot of l_t on age for *Salvelinus alpinus*. (Data from GRAINGER, 1953.)

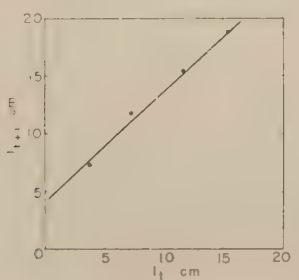

Figure 4. Plot of l_{t+1} on l_t with regression line for *Salmo gairdnerii*, Crater Lake, Oregon. (Data from HASLER, 1938.)

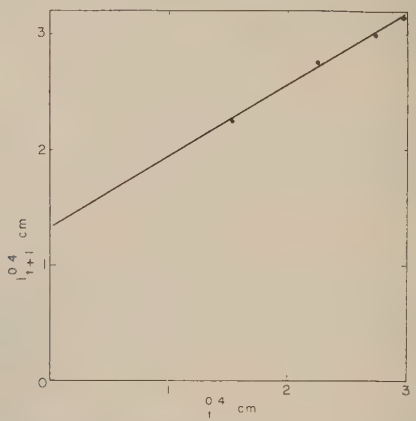

Figure 5. Plot of $l_{t+1}^{0.4}$ on $l_t^{0.4}$ for *Salvelinus gairdnerii*, Crater Lake, Oregon. (Data from HASLER, 1938.)

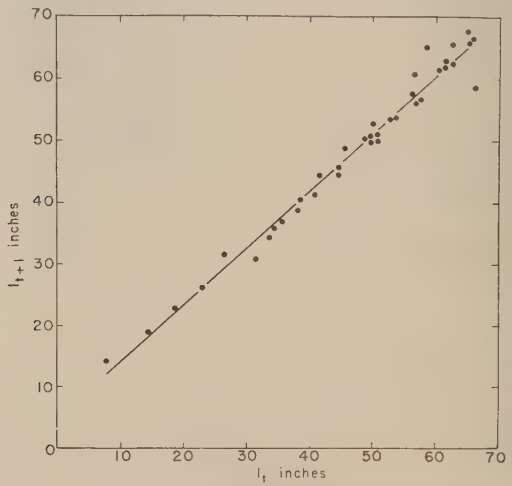

Figure 6. Plot of l_{t+1} on l_t for *Acipenser fulvescens*. (Data from PROBST and COOPER, 1954.)

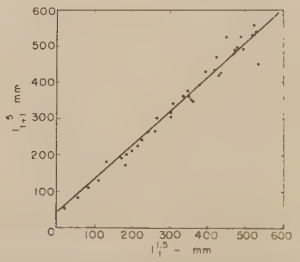

Figure 7. Plot of $l_{t+1}^{0.5}$ on $l_t^{1.5}$ for *Acipenser fulvescens*. (Data from PROBST and COOPER, 1954.)

from which one estimates $L_\infty = 66{\cdot}5$ inches, $K = 0{\cdot}0814$, and $A_{0.95} = 36{\cdot}8$ years.

Figure 7 shows the sturgeon data plotted as: —

$$l_{t+1}^{1{\cdot}5} = 0{\cdot}9475\, l_t^{1{\cdot}5} + 30{\cdot}88 \tag{35}$$

from which $L_\infty = 70{\cdot}2$ inches, $K' = 0{\cdot}0539$, and $A_{0.95} = 55{\cdot}6$ years. While the transformation improves the linearity, one can hardly claim any improvement of the estimated parameters. The oldest fish average 67·7 inches at 40 years. Upward concavity in a growth curve when plotted as l_{t+1} on l_t can be an artificial effect and caution should be exercised in applying equation (15) to such data (see Discussion).

Discussion

Surface area, body weight, and metabolism

We are taught by elementary mathematics — and by ARCHIMEDES himself — that in similar figures the surface increases as the square, and the volume as the cube, of the linear dimension.

The concept thus expressed by THOMPSON (1917) is esthetically pleasing and without exception in similar figures. Nature, however, may circumvent an outward appearance of similarity in a variety of ways, increasing certain areas enormously with respect to body volume by such devices as gill and lung structures.

In many animals, nevertheless, there is often a good correlation between external surface area and metabolism measured as oxygen uptake (PROSSER *et al.*, 1950). In warm-blooded animals, the external surface area may limit heat loss, but even here there are a variety of modifying mechanisms including the efficiency of insulation of the surfaces (PROSSER *et al.*, 1950) so that the relation to body weight may be altered.

In a study of dogs of different sizes, RUBNER (1883) found that the metabolism, measured as oxygen consumption under comparable conditions of almost complete rest and constant temperature, was not simply proportional to the weight but approximately to the weight to the $\frac{2}{3}$ power, which represents more or less closely the surface area. Thus equation (28) expresses "RUBNER's rule" when written as: —

$$dM/dt = kw(x = \tfrac{2}{3}) \tag{36}$$

This relation is also called the "surface law" or the "two-thirds rule" of metabolism.

PARKER and LARKIN (1959) and RICKER (1960) criticize the derivation of the Bertalanffy equation (7) because equations (3) and (4) imply the validity of the surface law of metabolism. Observed values of the exponent x in equation (28) frequently depart considerably from $\frac{2}{3}$. Experimentally determined values of x for fishes range from about 0·5 to 0·9 (FRY, 1957). Thus $\frac{2}{3}$ is at best only one of a range of values which x may take.

Equations (9) and (10) suggest writing equation (28) as: —

$$dM/dt = kw^{(x=a/b)} \tag{37}$$

This equation is equivalent to the conclusion of BRODY (1945) that it is the "metabolically effective" weight which must be considered and it is supported by ZEUTHEN's (1947) findings in studies of the respiration of marine microfauna that comparisons of organisms on the basis of nitrogen content are better related than comparisons based on weight and volume. It appears likely, therefore, that attempts to evaluate the parameters a and b by direct measurement of the surface area and weight of fishes would be attended by the same failure BRODY (1945) encountered in attempting to correlate surface area and body weight with metabolic rate in mammals.

Limiting values of parameters

Plausible limiting values of the quantity $(b–a)$ may be set even though a and b may not be readily determined. Since values of x $(x = a/b)$ greater than 1 in equation (28) have not been reported, to my knowledge, $(b–a) = 0$ is a likely limiting value, the limit resulting in exponential growth. Because the condition necessary for the logistic equation requires values of x greater than 1, this equation appears thus excluded on other than an empirical basis. This is hardly a loss, for the condition $(b–a) < 1$ adapts equation (14) to the fitting of growth data showing a point of inflection.

The condition $(b–a) = 1$ leads to the Bertalanffy and Ford-Walford equations. In case 1 a (1) it is pointed out that this indicates much greater generality than the restriction of values of a and b to 2 and 3 respectively.

Thus a reasonably plausible range of values of $(b–a)$ may be: –

$$0 \leq (b–a) \leq 1$$

It remains to be considered whether or not $(b–a)$ may be greater than 1.

When $(b–a)$ is greater than 1, it will be found that the plot of l_{t+1} on l_t is concave upward as in Figure 6. This type curve is so frequently observed in plots of growth data that one might conclude that it represents a pattern of growth. RICKER (1958, Figure 9·4 B), for example, shows this as one of the principal types of the Walford graph of l_{t+1} on l_t.

In examining the literature of fish growth data, I have yet to encounter an example of upward concavity in the plot of l_{t+1} on l_t where it is clear that this is not a result of the method of combining and averaging the growth of fish at several ages at capture. When fish growth data are separated by age at time of capture, the plot for each age typically shows an increasing slope and a decreasing intercept of the regression line with increasing age at capture. This, of course results in upward concavity when the data are combined and may lead to fallacious interpretations. CARLANDER and WHITNEY (1961, Figure 2) show an excellent example of this effect, and they interpret the effect correctly.

On the other hand, if the upper limit of $(b–a)$ is 1, there ought to be an interesting and theoretical reason for it. Until such reason is offered, it is suggested that, whatever values of $(b–a)$ are used in graduating growth data, due consideration must be given to the various artifacts which may arise from methods of combining and averaging. Some of these are discussed by RICKER (1958). PARKER and LARKIN (1959) show how a Bertalanffy curve may be "forced" on growth data as a result of the method of combining and averaging.

The limit $K = 0$ in the derivation of the parabolic growth equation indicates that the surface concept of metabolism is invalidated only quantitatively by the generalizations offered in equations (9), (10), and (28). Substituting ql^b in equation (10) for w in equation (28): —

$$dM/dt = k(ql^b)^{a/b}$$
$$= k'l^a$$

where $k'l^a$ is only another way of writing s in equation (9). Thus the derivation of the parabolic equation from (12) and the method of derivation used by PARKER and LARKIN (1959) is essentially equivalent.

The point of inflection

It is popularly supposed that a growth equation should show a point of inflection in length, a characteristic of equations (13) and (14) when $(b–a)$ is less than 1. Points of inflection in the relation of the part to the whole have been well demonstrated (e.g., MARTIN, 1949), and many organisms in nature do show a point of inflection in linear growth. Often, however, the inflection point may be associated with some factor of the external environment, leading one to suspect that a general growth principle may not be involved.

Autumn and winter spawned fish show typically a slow but accelerating growth, a marked acceleration with spring, and inflection during the summer and an apparent approach to an asymptote with the onset of winter. This pattern of growth actually relates closely to the temperature regime.

Similarly, shellfish following the larval stages settle so thickly at times that initial growth is badly inhibited. Rapid growth and an apparent inflection occur when predation and other mortality afford sufficient room for survivors, or when the individuals are transferred to more favourable locations (SPEAR and GLUDE, 1957).

In one carefully controlled experiment in fish growth, evidence of a point of inflection is entirely lacking. KINNE (1960) conducted experiments on the growth of the desert pupfish (*Cyprinodon macularius*) under several combinations of temperature and salinity. This euryhaline fish attains maturity in less than a year and KINNE made measurements of growth at two-week intervals from the time of hatching. Fish were held at five constant temperatures in water of 35‰ salinity, and in four different salinities at a constant temperature of 30°C. The growth is described accurately by regression equation (16) and Bertalanffy equation (7). The relation between the logarithm of K and temperature appears to be linear (Figure 8). The slope of the regression line in Figure 8, 0·0255, is much less than similar slopes, averaging about 0·075, observed for the cod, razor clam, and Pacific cockle (TAYLOR, 1960).

Compensatory growth

The phenomenon called "compensatory growth" or "growth compensation" carries in its name, and too frequently in the discussion of it, the unfortunate implications that the slow growing fish eventually gets a just reward and that a proper punishment will be exacted from the fish that initially grows too fast.

Equations (15) and (16) define the phenomenon quantitatively and objectively. Let d_t be the increment in length between ages t and $t + 1$: —

$$d_{t+1} = l_{t+1} - l_t \qquad (38)$$

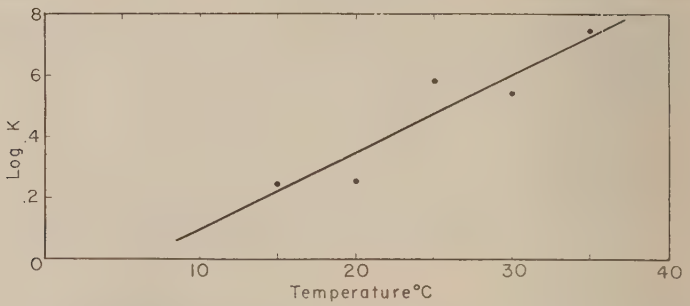

Figure 8. Regression of $\log K$ on temperature for the desert pupfish at five constant experimental temperatures.

From equation (16) the general result is obtained: —

$$d_{t+1} = m^{(t-1)}[l_1 (m-1) + i] \tag{39}$$

This is a linear equation with negative slope m^{t-1} $(m-1)$ and the intercept on y-axis at $im^{(t-1)}$. When l_1 is small, the subsequent increment will be larger and vice versa. The intercept of the line on the x-axis is an estimate of L_∞. The equation assumes that m and i are constants, therefore implying that K and E are constant or that the condition for linearity is constant environmental conditions.

Equation (39) may be written directly from knowledge of the parameters m and i in equation (16), but because these parameters are determined from lengths at a number of ages, the parameters of equation (39) as determined from plotting the increments, d_t, on l_1 may be different.

When mean l_{t+1} is plotted on mean l_t for the 1937 to 1954 year-classes of Pacific sardines (*Sardinops caerulea*) landed as 4 year-olds at San Pedro, California, the following regression is obtained: —

$$l_{t+1} = 0{\cdot}5325\ l_t + 104{\cdot}92 \tag{40}$$

From equation (40), equation (39) is written directly as: —

$$d_2 = -0{\cdot}4675\ l_1 + 104{\cdot}92 \tag{41}$$

Figure 9 shows the increments, d_2, plotted on l_1 for these same data. The regression equation, to be compared to equation (41), is: —

$$d_2 = -0{\cdot}4480\ l_1 + 103{\cdot}33 \tag{42}$$

Over the 18-year period during which the data were collected, strict linearity in this relation is not expected. Nevertheless, the correlation between d_2 and l_1 is 0·827 (16 d.f., $p < 0{\cdot}01$). Equally good relations between d_2 or d_3 and l_1 are observed for sardines of other ages at capture.

From equation (40) one estimates $L_\infty = 224{\cdot}4$ mm, $K = 0{\cdot}63$. From equation (41) the estimates are: $L_\infty = 230{\cdot}6$ mm, $K = 0{\cdot}59$. Thus a fairly good estimate of the growth curve for 4 year-old sardines is obtained from information on the lengths at ages 1 and 2 only. This result suggests a method of obtaining a tentative growth curve from minimum data, that is, for fish the lengths of which can be determined only for the first two years.

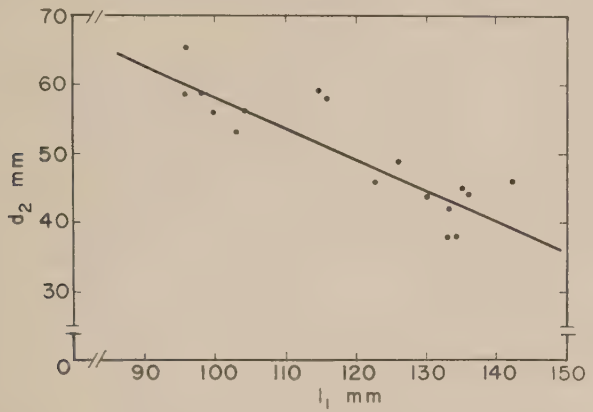

Figure 9. Regression of d_2 on l_1 for the 1937 to 1953 year-classes of sardines captured at age 4 at San Pedro, California.

Problems in estimating parameters

Values of $(b–a)$ used in the illustrative examples in this paper are trial values arrived at when the plot of $l_{t+1}{}^{(b-a)}$ on $l_t{}^{(b-a)}$ appeared suitably linear. For the Arctic char data, it was further determined that the sum of the squares of the deviations of calculated values of l_t from observed values of l_t was less than that for the neighbouring values of $(b–a)$ of 0·35 and 0·25.

While this procedure is laborious, there are several clues which help reduce the computations. Reasonable values of L_∞ and $A_{0.95}$ are usually known and if there is an inflection point in the data it is quickly determined by plotting l_t on t. Unsuitable trial values of $(b–a)$ lead to unrealistic estimates of L_∞ and $A_{0.95}$ and to a misplaced point of inflection. The criterion of linearity in the plot of $l_{t+1}{}^{b-a}$ on $l_t{}^{b-a}$ is helpful, but visual estimates cannot be relied on to obtain optimum values.

The problem of estimating the parameters of non-linear regression equations has been the subject of an extensive literature in recent years. References particularly pertinent to fitting a Bertalanffy-type regression are Stevens (1951), Gomes (1953), Chapman (in press), and Tomlinson and Abramson (1962).

Validation of growth theory

Because the parameters of the Bertalanffy equation, and the more general statement of that equation in this paper, are derived from physiological considerations, it should be possible to relate them to various factors known to affect the processes of anabolism and katabolism or to phenomena which may be related to these processes, such as mortality rate and longevity.

Beverton and Holt (1959) have compared values of the parameter K with longevity in fishes. The relations found are suggestive, but the lack of any marked success may result from their comparisons of average values of K with exceptional records of longevity.

In three marine species Taylor (1958b, 1959, 1960) has shown that the

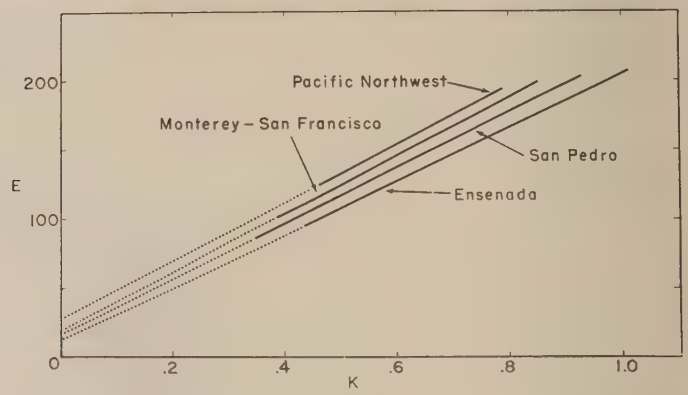

Figure 10. Regressions of K on E for sardines, ages at capture 3 to 6, landed at ports indicated.

logarithm of K is linearly related to environmental temperature. TAYLOR (1958a) concluded from an analysis of back-calculated growth for haddock at different ages at capture that K defines a "physiological" mortality rate and a "life-span." While HOLT (1959, 1960) has criticized the latter concepts, he has suggested (personal correspondence) the need for a more rigorous definition of $A_{0.95}$, a suggestion with which I fully agree.

There is experimental evidence (FRY, 1957) to indicate that changes in food supply affect the overall metabolic rate, not merely the rate of anabolism. TAYLOR (1959) has remarked that the indication of linearity between the parameters K and E for many fish species is evidence that the rate of anabolism does not fluctuate independently of katabolism.

More detailed information on the growth of the sardine (*Sardinops caerulea*) suggest possible qualification of this observation. Figure 10 shows the regressions of K on E for sardines, ages at capture 3 to 6, landed at the ports of Ensenada, Baja California; San Pedro and Monterey — San Francisco, California; and ports in the Pacific Northwest (Oregon, Washington, and British Columbia). The slopes of the regressions of E on K do not differ significantly, but the elevations of the lines do. The north-south cline in values of E may be associated with differences in zooplankton abundance which in turn is related to differences in average water temperature (REID *et al.*, 1958, Figure 23). The possibility that these differences are genotypic must not be overlooked (SPRAGUE and VROOMAN, 1962).

The biological implications inherent in growth equations may be tested by experiment. In view of their importance to the interpretation of growth data and in fishery dynamics theory, such experiments are badly needed. The experiments of KINNE (1960), as one example, show clearly that estimates of the parameters K and E can be derived from experimental growth studies and can be compared to experimental conditions. Techniques are at hand for testing the effects of environmental factors on growth rate, mortality rate, and longevity. Thus it appears possible to test the validity of the reasoning advanced by BERTALANFFY in his 1938 paper, the consequences of which have been explored a step farther here.

Summary

Growth in weight is the difference between anabolic and katabolic processes. These are taken as proportional to length to the power of a and b. Equations giving the length at any time, and also relating length to the power of b–a at successive times are deduced. If $b-a = 1$ these reduce to the Bertalanffy equation and the Ford-Walford plot. Other values of a and b may produce parabolic growth, or an inflection in curve of growth in length. Possible values of a and b based physiological data are discussed, as are changes in the other growth parameters with environmental factors, including food and temperature.

The methods are applied to data of several species, including char, sturgeon, and sardine.

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MEASURING THE PRODUCTION OF MARINE PHYTOPLANKTON. *By J. D. H. Strickland. (Fisheries Research Board of Canada, Bulletin No. 122). The Queen's Printer, Ottawa. 1960. 172 pp., 9 tables. $2.00.*

The author states that there is "no comprehensive and critical review of marine primary productivity that serves as an adequate introduction to the subject in all its aspects for workers about to commence active research in this field." In this publication the author attempts to satisfy this need by presenting in clear, concise language an excellent introduction to the measurement of primary productivity of marine phtyoplankton. Not only is he successful in providing a valuable text for new workers, but also he raises questions which might profitably be further examined by researchers already in the field.

The publication is divided into five sections. A table of contents, a glossary of symbols and abbreviations, introductory remarks, and an extensive bibliography are also included.

In any introductory text an author is confronted with the problem of using terms, which although familiar to the experienced worker, are unknown to the neophyte. The author, realizing this, has devoted an entire section to a compact, yet thorough, discussion of definitions and conversion factors.

In a discussion of the chemical composition of phytoplankton in Section II the author adequately covers the elementary composition, the major molecular constituents, and the pigments used in measuring primary productivity. Briefly covered in each instance is a review of the literature, the relationship between constituents, the degree of variations in measurements and their causes, and the limitations of values determined for each constituent as used in reporting the findings. Possible solutions for some of the problems which arise when measuring chemical composition of phytoplankton are given, and several techniques with their limitations used for obtaining these measurements are introduced.

The primary problem of measuring a standing crop of organisms is to obtain a representative sample of a population which is distributed unevenly over an extensive area. In Section III the author covers the problem of gear selection, of processing the sample, and of separating phytoplankton from all organic matter of animal origin and detritus. This is followed by a discussion of the techniques employed in estimating primary productivity from carbon content, nitrogen, phosphorus, and specific organic constituents, and by pigment analysis. Discussing each phase separately, the author provides a brief review of the literature succeeded by a discussion of the limitations. This section is terminated with a discussion of some results of standing crop determination obtained by various workers.

Section IV, a discussion of the measurement of the rate of photosynthesis, is by far the best portion of the text. Introducing this topic, the author provides an informative discussion of oxygen and carbon dioxide requirements and relationships, photosynthetic and respiratory quotients, effects of illumination on respiratory algae, and participation of intracellular material and the interpretation of radiocarbon productivity measurements. The problem of sampling and direct measurements is discussed again, and although slightly repetitious of Section III, this additional coverage is beneficial to the neophyte in that it provides further insight into the problems encountered in the field and laboratory. Having presented this background information, the author then covers the measurement of the rate of photosynthesis by carbon dioxide consumption, the oxygen evaluation (dark and light bottle), the rate of carbon-14 uptake, methods based on pigment content, and finally by other methods which involve depth profiles of oxygen or phosphorus concentrations and the uptake of phosphorus. In each instance he provides a brief review of the literature, general techniques, limitations, and special considerations to be taken into account. Terminating the discussion of measuring the rate of photosynthesis, the author provides a table and brief discussion of selected examples of productivity measurements.

Section V is "a detailed discussion of the measurement of primary productivity in nature and of methods designed to predict *in situ* productivity with the minimum amount of experimentation." Before delving into this subject, the author provides a brief discussion of the concept of the productivity index of a water mass. Then, in a discussion of general kinetics, the author covers the kinetics of unicellular growth and decay, the influence of light, and the diurnal fluctuation of organisms as related to timing of experiment. Concluding the text, productivity measurement in nature is presented with the author providing additional observations on population changes in nature and the *in situ* production and its prediction from experimental work using light incubators.

Mr. Strickland has shown that he is well acquainted with his field, and the direct, clear manner in which the material is presented is to be commended. The reference section, although not covering the entire field, is an adequate introduction to the beginner as well as a usful tool to the experienced worker.

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RATE OF METABOLISM AND FOOD REQUIREMENTS OF FISHES. *By G. G. Winberg. (Fisheries Research Board of Canada, Translation Series No. 194). (Published in Nauchnye Trudy Belorusskovo Gosudarstvennovo Universiteta imeni V. I. Lenina, Minsk, 253 pp., 1956). Fisheries Research Board of Canada, Biological Station, Nanaimo, B. C. 1960. 202 pp., 54 figs., 32 tables.*

This translation of G. G. Winberg's monograph represents a cooperative enterprise of the Fisheries Research Board of Canada, the Department of Zoology of the University of Toronto, and the Research Division of the Ontario Department of Lands and Forests.

Much of the monograph is devoted to reviewing the various relationships of the metabolic rate of fish to factors such as temperature, the oxygen content of water, total body size and weight, salinity, diurnal fluctuations in metabolism, and differences between species. In this discussion he is concerned

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RECORDS OF RINGED SEALS FROM THE PRIBILOF ISLANDS

A ringed seal *Pusa hispida* collected in 1951 has represented the first record for the Pribilof Islands, Alaska (Kenyon, J. Mamm., 41: 520). On 21 June 1961, one of us (T), with Eugene Lyons, saw a small seal basking on the rocks at Polovina Point, St. Paul Island. We captured, photographed and measured it (70 cm from snout to tail tip); then released it. The stout fore-flipper claws and ring-like markings on the pelage, seen in life and on photographs, distinguish it from the harbor seal *Phoca vitulina*, a common resident there.

On 26 July 1961, Aleut workmen brought to one of us (S) the warm body of a ringed seal which they had clubbed on the village beach at St. George Island. It was a female; estimated age 3 months; length 110 cm. Its white wooly birthcoat was almost gone and was subsequently lost when the skin was tanned. The skin, with fragmental skull, is specimen 26-7-61 A in our Seattle laboratory. It represents the first record from St. George Island. We suspect that a few ringed seals may visit the Pribilofs each year in spring, since drift ice regularly comes as far south as one or both of the islands.—REX THOMAS AND VICTOR B. SCHEFFER, *Fish and Wildlife Service, Seattle 15, Washington.* *Received 20 November 1961.*

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Reprinted from TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY
Vol. 91, No. 3, July, 1962
pp. 321–323

Herring Predation on Pink Salmon Fry in a Southeastern Alaska Estuary

Pink salmon fry (*Oncorhynchus gorbuscha*) are about 30 millimeters long when they emerge from their spawning beds and migrate to salt water in the spring. Migration usually takes place during the hours of darkness, and most fry move immediately into the estuary. Here they must adjust to a completely new environment.

Studies of the estuarine environment and the transition of pink salmon fry from fresh to salt water are being made at Little Port Walter on the southern tip of Baranof Island in southeastern Alaska. In the spring of 1960, Pacific herring (*Clupea harengus pallasi*) were observed actively feeding on young salmon. Results of this study to learn the degree of predation indicate that the Pacific herring may be a serious predator of pink salmon fry in this area.

Investigations of the food habits of both Atlantic (*Clupea harengus harengus*) and Pacific herring have shown that both species feed principally on zooplankton, chiefly copepods and euphasids. Rudakova (1959) notes that, in addition to plankton, Atlantic herring consume substantial quantities of juvenile fishes during the spring, summer, and autumn months. He found young cod, herring, rockfish, sand lance, and lanternfish in stomach contents. I have been able to find no published record that lists salmon fry in the herring diet. Charles E. Walker (personal communication, November 1960) observed herring chasing and eating fry in Uyak Bay, Kodiak Island, Alaska, during 1958 and 1959. He also examined the stomachs of herring captured by beach seine in Browns Lagoon, Uyak Bay, and found as many as 10 fry in a single stomach.

At Sashin Creek, Little Port Walter, the downstream migration of pink salmon fry begins in late March, peaks in mid-May, and ends by mid-June. The young salmon remain in the estuary until they reach a length of about 40 millimeters, when they move out into Lower Chatham Strait. Young salmon are seldom found in the estuary after the first week in July. Herring appear sporadically in the estuary at all times of the year, and often concentrate there in large schools during the spring and summer months.

The downstream migrant salmon at Sashin Creek are trapped, counted, and released each year at a weir at the mouth of the stream. During the peak of the emigration, counts and releases are made at half-hourly or hourly intervals, and as many as 85,000 fry are released at one time. Migrants trapped during daylight hours are generally held for release the following evening.

Early in May 1960, after releases of salmon fry, herring were observed apparently feeding near the water surface in a constricted area of the bay at the mouth of the stream below the weir. On the morning of May 10, a beach seine haul was made in this area to capture live herring and determine if they were feeding on fry. The stomachs of 101 herring were examined. Thirty-six contained from 1 to 32 fry, an average of 10.9 per stomach. As a result, more intensive studies were made to learn the extent of the herring predation.

Herring were captured by beach seine and gill net (1½-inch, stretched measure) during hours of daylight and darkness, and before and after fry releases. All catches were made in the constricted part of the bay near the stream mouth. Shortly after capture each fish was examined, and the fork length in millimeters, sex, and stomach contents were recorded. Since the primary interest was the presence or absence of fry, individual food items other than fry were not counted, nor were measurements of volume or weight taken.

Results of the stomach analyses are presented as frequency of occurrence (Table 1), with each food item given equal weight regardless of the number consumed. Between May 19 and 26, 436 stomachs were examined. Forty-seven (10.8 percent) were empty, and 389 (89.2 percent) contained food. There

TABLE 1.—*Stomach contents of herring examined at Little Port Walter, Alaska, May 19–26, 1960*

Item	Frequency of occurrence	Percent occurrence in all fish examined	Percent occurrence in fish with food in stomachs
Pink salmon fry	250	57.3	64.3
Sculpin	1	0.2	0.3
Isopod	74	17.0	19.0
Mysid	14	3.2	3.6
Caddis fly	2	0.4	0.5
Herring eggs	10	2.3	2.6
Spruce and pine needles	7	1.6	1.8
Catkin	1	0.2	0.3
Wood	1	0.2	0.3
Plant material	1	0.2	0.3
Unidentified	162	37.2	41.6
Number of herring with empty stomachs		47; 10.8 percent	
Number of herring with food in stomachs		389; 89.2 percent	
Total examined		436	

were no apparent differences in the stomach contents of herring by sex or of those captured by different types of gear, and the results have been combined. Pink salmon fry were found most frequently, occurring in 64 percent of the stomachs of feeding fish. Isopods were identified in 19 percent, and mysids in 3.6 percent of the stomachs. Most of the unidentifiable material appeared to be digested mysids, but positive identification could not be made.

Pink salmon fry were found in 250 stomachs. The number of fry per stomach ranged from 1 to 69, with a total of 4,505. This is an average of 18.0 per stomach for herring feeding on fry, whereas the average for all stomachs examined was 10.3. Although the number of herring in the Little Port Walter estuary during the period when pink salmon fry passed through is not known, the number of fry they consumed may be quite high.

Pink salmon fry were found in stomachs throughout the size range of herring in the sample (148–277 mm.). Their frequency of occurrence in herring stomachs indicates that all herring in the size range sampled were equally capable of capturing fry, and that no size group preferred pink salmon fry more than another.

The water of the Little Port Walter estuary has a sharp salinity stratification as a result of the discharge from Sashin Creek; the surface layer is less saline than the deep water. Although pink salmon fry usually inhabit the less saline surface water and herring the more saline deep water, herring frequently foraged through schools of fry in the upper layer. Individual herring could be seen rising from the deep water to strike at fry at the surface. At times, especially after fry had been released at the weir, the water's surface at the head of the bay was broken by hundreds of herring. They appeared to feed less actively at low than at high tide, possibly because of a greater concentration of fresh water at the head of the bay at low tide.

The numbers of fry in the stomachs of herring captured by beach seine before and after fry releases were compared to determine whether predation was more severe when fry were first released than at other times. The rate of digestion is governed by water temperature, and according to the observations of Battle *et al.* (1936), it was estimated that 20 hours would be required for stomachs to clear at the prevailing sea water temperature (5° C.) in Little Port Walter estuary. Therefore, the relative intensity of predation could be measured only by the presence or absence of freshly ingested fry. Such fry were commonly found in the stomachs of herring captured 8 hours or more after a release, but invariably there were more in stomachs of herring captured from 15 minutes to 1 hour after. It is not known whether or not the sudden release of large numbers of fry causes the rate of predation to be greater than it would be if the same numbers of fry were allowed to enter salt water naturally. Walker's Uyak Bay observations indicate that predation occurs naturally, but probably at a lesser rate than shown by this study.

Since for most fry the critical transition from fresh to salt water is made during darkness, the hypothesis was made that predation might be less during darkness than during daylight. To test this hypothesis an analysis was made of the number of herring found with freshly ingested fry in their stomachs during the two periods. Results of the analysis indicate that the odds are on the order of 200 to 1 that fewer herring with fry in their stomachs would be captured during the dark than during the daylight hours (chi square = 9.78; $d.f. = 1$, $P < .005$). Although sampling was confined to a short period, these limited observations suggest that herring feed most actively on pink salmon fry during the day, and also that the protective advantage of the

nighttime migration applies also in the estuary.

The addition of herring to the list of salmon predators does not necessarily imply that predation by herring is general. The extent and areas of predation are not known. The Little Port Walter observations and those of Walker at Uyak Bay demonstrate that predation does occur in widely separated areas.

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BIOLOGICAL OBSERVATIONS OF STELLER SEA LIONS TAKEN DURING AN EXPERIMENTAL HARVEST

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Steller sea lions (*Eumetopias jubata*) have been the subject of recent studies in Alaska because of their alleged depredations on salmon and halibut fisheries. Mathisen (1959) estimated that a minimum of 150,000 sea lions inhabited Alaskan waters. Kenyon and Rice (1961), on the basis of more complete observations in the Aleutian Islands, have estimated a minimum of 181,892 animals. With the twofold purpose of possibly reducing the sea lion herds and providing an economical high protein meat for fur farms, fish hatcheries, and similar purposes, the Bureau of Commercial Fisheries awarded a contract to a commercial fishing company in the spring of 1959 to develop techniques for harvesting sea lions in Alaskan waters.

In conjunction with the harvest, biologists accompanied the expedition. This paper reports their observations on (1) sea lion behavior and their reactions to hunting, and (2) reproduction, growth, sex and age composition of the population; natural mortality, and food habits. Because the commercial aspect of the expedition was of primary importance, the biological data were taken in a manner that interfered as little as possible with the hunting and processing activities. Consequently, it was not possible to examine each animal taken or to make observations on undisturbed rookeries.

The freezer ship *Arctic Maid* served as a base of operations, and sea lions were harvested from five major rookeries between Kodiak and Krenitzin Islands (Fig. 1). Between May 27 and July 15, 464 animals were taken from Marmot, Atkins, Ugamak, Jude, and Chowiet Islands. Commercial aspects of the experimental harvest have been reported by Thorsteinson, *et al.* (1961).

We would like to express our thanks to biologists Dexter Lall, formerly of the Bureau of Commercial Fisheries, and Paul Garceau of the Alaska Department of Fish and Game, who accompanied the *Arctic Maid* and carried out much of the field work during the expedition.

BIOLOGICAL OBSERVATIONS

Behavior

Sea lions are strongly social and throughout the year gather on offshore rocks or small islands in groups that vary from a few to many thousand animals. During the breeding season from May to July, however, many winter hauling places are abandoned, and the animals concentrate on rookeries. At this period the population is more sedentary than at other times, and animals are more difficult to disturb. These features of sea lion behavior determined the scheduling of the experimental harvest.

The most significant characteristic of sea lion behavior affecting experimental harvest was the strong territorial attachment of polygamous breeding bulls. De-

[1] Lensink was associated with the Alaska Department of Fish and Game during this study.

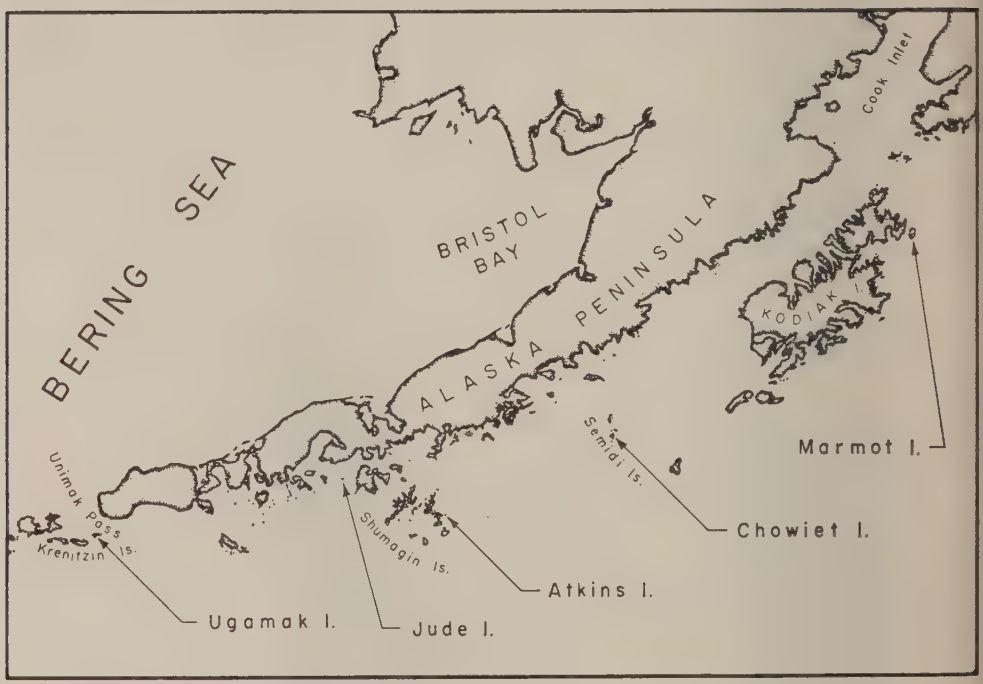

FIG. 1. Alaska Peninsula, showing islands where sea lions were harvested, 1959.

fense of territories resulted in segregation of nonbreeding bulls from harem areas. As with fur seals (Bartholomew, 1953), the apparent basis of the social behavior of female sea lions is gregariousness, and territorial attachment is weak or lacking.

Sea lions usually showed little alarm at the approach of boats used by hunters, and only a few bachelor bulls moved into the water. When shooting began, however, most bachelor bulls and females without pups rushed to the water, and remaining animals, including many females with pups, crowded to the inner margins of the rookery. Harem bulls usually remained on their territories, or if they did leave, returned almost immediately.

Animals that entered the water did not attempt further escape but stayed near shore and watched the hunters on the rookery. Sea lions did not appear interested in the fishing boat close by or the small skiff operating between boat and shore.

Cows with young pups that remained on the rookery occasionally charged members of the hunting crews, but such charges always stopped short of actual attacks. Sometimes cows grasped their pups by the neck and carried them to safety in the water, occasionally swimming as far as 100 yd before returning to shore. Cows leaving the rookery without their pups frequently returned to shore soon after shooting ceased, despite the presence of hunters.

At the peak of the breeding season or at the beginning of hunting on a rookery, animals started to return to shore soon after the hunters left. Animal wariness increased with continued activities of hunting parties and with the decline in breeding activity. Continued hunting over the same area caused an emigration to nearby rocks or a lateral movement along the beach if space was available. Emigration began after 3 to 5 days' harassment, and eventually a decline in number of animals in the hunted area was observed.

TABLE 1.—REPLACEMENT OF HAREM BULLS ON UGAMAK ISLAND ROOKERY DURING 7 DAYS OF HUNTING, 1959

Date	Bulls Present	Bulls Killed or Wounded
June 26	25	24
June 27	25–30	22
June 28	29	14
June 29	27	14
June 30	No count	13
July 1	No count	17
July 2	18	10
Total		114

The harvest consisted chiefly of harem bulls, because their reluctance to leave the rookery made them more available to hunters than the easily frightened cows, and also because from two to three times as much meat could be obtained from males as from females for about the same expenditure of time.

Bachelor bulls quickly replaced harem bulls taken from territories. At Ugamak Island, 114 territorial bulls were taken from a harem area less than 100 yd long in 7 consecutive days of hunting. The number of bulls available per day on this section of the rookery was never more than 30 nor fewer than 18 (Table 1). At Marmot Island, 83 bachelor bulls were counted in an area adjacent to the hunted harem area. Although few of these were killed, their number diminished to approximately 20. The daily count of harem bulls in the hunted area did not change appreciably, and the continued presence of harem bulls suggests that replacement of territorial males is common, and that bachelor bulls are continually attempting to invade the harem area.

Reproduction

Harems were established and a few pups were present on the Marmot Island rookery when harvesting began on May 27. By June 5 the number of pups had reached about 30. No further increase in the number of pups was observed on June 9, nor were fresh umbilical cords noted on pups examined on that date. A 46-lb male fetus was found, however, in a female examined on June 21. Scheffer (1946) states that on Saint Paul Island, one of the Pribilof group, the 1944 season of parturition extended for about 4 weeks, from May 23 to June 20, and was at a peak about June 6.

Breeding activity was at a high level at all rookeries visited between May 27 and July 1, and harem disintegration was rapid after July 10.

The testes were taken from 160 bulls and preserved in 10-per cent formalin. The fixed testes were weighed to the nearest gram, and smears were made from the epididymides for identification of sperm. All smears contained sperm. Testis weights were about the same for animals in age groups 6 to 17 (Table 2).

Brooks (1957) concluded from observations of many cows with nursing yearlings that biennial breeding is characteristic of sea lions. Cows with yearlings were numerous on all rookeries observed in 1959 and usually occupied different areas (or even separate rookeries) from cows with newborn pups. On the portion of the Marmot Island rookery that was observed, there were many more cows with yearlings than with pups.

Pike and Maxwell (1958) indicate a pregnancy rate in excess of 70 per cent for sea lions in British Columbia. This is comparable to a 69-per cent rate reported by Kenyon, *et al.* (1954) for the northern fur seal (*Callorhinus ursinus*), a species that breeds annually. It is possible that the pregnancy rate on some Alaskan rookeries may be of the same order, but our

TABLE 2.—TESTIS WEIGHTS OF HAREM BULLS TAKEN DURING EXPERIMENTAL HARVEST

Age	Sample Size	Testis Weight (g)		Standard Error (g)
		Range	Mean	
6	1		86.0	
7	3	48–115	85.7	19.8
8	6	33–117	81.2	11.8
9	19	77–122	95.9	2.8
10	49	68–117	89.2	2.3
11	38	64–117	92.0	2.3
12	20	52–124	88.5	4.6
13	14	70–114	89.4	10.2
14	6	81–110	90.8	4.4
15	4	73–105	86.5	12.3

TABLE 3.—AGE DISTRIBUTION OF HAREM BULLS TAKEN DURING EXPERIMENTAL HARVEST, 1959

Age	Island Rookery and Dates Taken					Total
	Marmot 5/27–6/9	Atkins 6/12–6/23	Ugamak 6/26–7/8	Atkins–Jude–Chowiet 7/10–7/15	Unknown	
6			1			1
7		2	1	1		4
8		2	1	3	1	7
9	3	4	4	10		21
10	3	17	23	10	1	54
11	12	12	14	6		44
12	6	13	2		1	22
13	6	5	7		1	19
14	6	2				8
15		2	1			3
16+		1				1
17+		1				1
Total	36	61	54	30	4	185
Mean	11.8	11.2	10.6	9.6		10.8

observations and those of Brooks suggest that further investigations are required.

Age

The external rings on canine teeth were counted to determine ages of the sea lions, a method described by Scheffer (1950) for the northern fur seal. Ages were also determined (by Lensink) by cutting each tooth through the midsagittal plane, polishing one of the halves, and counting the internal laminations. The teeth were sent to the Marine Mammal Biological Laboratory, Seattle, Wash., for separate age determinations, which were made by C. H. Fiscus, Jr. Disagreements between Lensink's and Fiscus' determinations occurred in 46 per cent of the sample, but most involved differences of 1 year and were readily reconciled. The disagreements were nearly compensatory, as Lensink classified nine animals 1 year younger, ten 1 year older, and two 2 years older than did Fiscus. The age distribution of animals for which there was disagreement approximated the age structure of the entire sample. In cases where no agreement could be reached (22 animals), Lensink's determinations were used.

The age distribution for a sample of 185 harem bulls ranged from 6 to 17 years. More than 90 per cent of the animals in the sample were from 9 to 13 years old (Table 3).

At Ugamak Island younger animals apparently replaced killed harem bulls. Table 4 shows that during the week of hunting the mean daily ages shifted toward younger animals.

The trend toward replacement of old harem bulls by younger males observed on Ugamak Island also appeared to be on a seasonal basis (Table 3). The mean age of harvested harem bulls decreased at each rookery as the season progressed. The shift toward younger animals, which progressed with time, strongly suggested seasonal replacement of older bulls. The age frequencies from the four periods of sam-

TABLE 4.—AGES OF HAREM BULLS KILLED ON UGAMAK ISLAND ROOKERY DURING 7 DAYS OF HUNTING, 1959

Age	Frequency of Occurrence						
	June 26	June 27	June 28	June 29	June 30	July 1	July 2
6		1					
7				1			
8					1		
9				1		2	
10	3	3	2		2	3	4
11	1	1		3	1		2
12	2						
13	2	3	1				
14							
15			1				
Total	8	8	4	5	4	5	6
Mean	11.4	10.8	12	9.8	9.8	9.6	10.3

TABLE 5.—LENGTHS OF ADULT MALE SEA LIONS TAKEN DURING EXPERIMENTAL HARVEST, 1959[1]

Age	Sample Size	Body Length (in.)	
		Range	Mean
9	8	106–118	113
10	22	106–123	115
11	22	107–122	116
12	16	111–122	117
13	14	110–124	118
14–17	9	114–129	118
Total	91		

[1] Nose to tip of tail; animal hung by neck.

pling were compared by Chi-square, and the differences are significant:

$$\text{Chi-square} = 82.8,\ \text{d.f.} = 33;\ P < 0.005$$

Probably all males are sexually mature when 6 or 7 years old, but most are physically (or socially) unable to compete successfully for harems until they are 9 or 10 years old. It is possible that the less frequent occurrence of animals aged 12 years or older as the season progressd is due to competition from younger animals for harem areas. The only debilitating factor observed that might result in inability of older animals to compete for territories is the erosion of canine teeth, which is increasingly severe in animals older than 12 years.

Ages in a sample of 10 adult females ranged from 6 to at least 13 years, but the sample was too small to establish a definite pattern of age distribution.

Length and Age

Length measurements (tip of nose to end of tail) were taken while the animals were suspended by the neck from a cargo boom. Although measurements taken in this manner were uniform, they would exceed those taken if the animals had been measured in a prone position.

Mean lengths for 91 adult male sea lions are given by age groups in Table 5. These data show that there is little increase in length after 9 years. The variability of lengths within each age class precludes length as an indicator of age for mature animals.

Baculum Weights and Age

Bacula were preserved by freezing and were later cleaned by boiling to remove fat and other organic material from the bone matrix. They were then air dried and weighed to the nearest 0.1 gram.

Baculum weights in a sample of 122 animals increased from an average of 32.6 grams for 8 animals 6 to 8 years old to an average of 41.7 grams for 8 animals 14 years old and older (Table 6). It is possible that the difference in baculum weights between young and old bulls is greater than indicated by our sample because it comprises only breeding bulls. Thus, the 6- to 8-year-old animals in our sample may be larger than other animals of the same age classes that do not or cannot hold territories. As with length measurements, variability in baculum weights within each age class precludes the use of baculum weight for age determination.

Natural Mortality

Moribund or dead animals were observed on rookery areas, but the number of adults found dead was small in respect to population size. Mortality of pups was high, and at Ugamak Island 60 pups, or about 10 per cent of those born on the area examined, were found dead in late June. They were nearly all less than a month old at the time of death.

The primary cause of juvenile mortality is not known, but contributing factors may be starvation resulting from death of the mother or desertion by her, or injuries resulting from contact with adults.

TABLE 6.—BACULUM WEIGHTS OF HAREM BULLS TAKEN DURING EXPERIMENTAL HARVEST, 1959

Age	Sample Size	Baculum Weight (g)	
		Range	Mean
6–8	8	25–42	32.6
9	19	30–46	36.8
10	38	25–54	36.9
11	29	26–52	37.3
12	9	34–49	40.6
13	11	33–51	40.1
14–17	8	28–51	41.7
Total	122		

TABLE 7.—OCCURRENCE OF FOOD ITEMS IN STOMACHS OF SEA LIONS TAKEN DURING EXPERIMENTAL HARVEST, 1959

Item	Island Rookery and Dates Taken					Total Frequency	Per cent[1] Frequency
	Marmot 5/27–6/10	Atkins 6/12–24	Ugamak 6/26–7/8	Jude 7/10–11	Chowiet 7/15		
Rockfish	2	2	2			6	11
Greenling	1	1				2	4
Cottids			2			2	4
Sand lance	7	2	5			14	25
Halibut		1				1	2
Flatfish		1	1			2	4
Lumpfish		1				1	2
Crab		5				5	9
Clam, Mussel, or snail		16				16	29
Squid or octopus	1	10	8	1		20	36
Milk[2]		1				1	2
Unidentifiable fish remains	1	4	5			10	18
Stones or gravel	44	54	43	5	8	154	
Total stomachs examined	70	141	126	30	10	382	
Total stomachs containing food	9	26	20	1	0	56	

[1] Per cent frequency based on stomachs containing food.
[2] Stomach of yearling.

Two species of external parasites were found, but their effect upon the animals is not known. Pups were severely infested with the body louse (*Antarctophthirus michrochir*), which was infrequently found on adults. Nose mites (*Orthohalarachne diminuta*) were invariably found on adults.

Food Habits

A qualitative examination of stomach contents was made in the field. The sample of 382 stomachs included those from 10 females. As there was no apparent difference in stomach contents between sexes, the results have been combined. Food items found were similar to those reported for sea lions in British Columbia (Pike, 1958) and Alaska (Mathisen, 1959). A wide variety of food was eaten, but insignificant amounts of commercially important species of fish were present.

Only 56 of 382 stomachs examined contained food (Table 7). The low incidence of stomachs with food indicates erratic feeding habits of bulls (which made up most of the sample) during the breeding season and may not be characteristic of samples taken at other seasons. Seven species of fish were identified. Halibut, the only commercially important species present, occurred in one stomach. Squid or octopus occurred in 20 stomachs and crabs in 5. Although clams, mussels, or snails occurred in 16 stomachs, they were represented only by shell fragments and may have been ingested with gravel or stones.

Large quantities of coarse gravel or even fist-size rocks were commonly found in stomachs. In nearly half of all stomachs examined, rocks were found in amounts frequently weighing more than 20 lb per stomach. Large size of the rocks would preclude their passage through the relatively small diameter of the intestine. When foraging for food begins, rocks and gravel are probably regurgitated, since actively feeding animals do not contain them. Local fishermen and hunters frequently remark on the presence of rocks in sea lions' stomachs, and their theories regarding the purpose of

the rocks run the gamut from a need for ballast to destruction of parasites. Laws (1956) shows that ingestion of stones by the elephant seal (*Mirounga leonina*) is probably an adaptation related to prolonged fasting by this animal, the distention of the stomach by stones serving to prevent hunger pangs.

SUMMARY

An experimental harvest of Steller sea lions was composed primarily of breeding bulls, because their pronounced territorial attachment and reluctance to leave rookeries made them easy prey for hunters. Killed harem bulls were quickly replaced by bachelor bulls. In a sample of 185 harem bulls, ages ranged from 6 to 17 years, with age classes 10 and 11 being dominant. Mean ages declined as the season progressed. Body lengths and baculum weights tended to increase with age, but the variability of these characters precluded their use as indicators of age. Growth of bulls is slight after 9 years of age. In stomach contents of 382 animals, including 10 females, only one commercially important fish (halibut) was identified.

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Science Follows the Fish

Tracking salmon by electrical sonic means, biologists find that, on their way to spawning grounds, fish usually travel near shore in water 30 feet deep or less

by Parker S. Trefethen

Photo by Oregon Fish Commission

The behavior of fish at Bonneville dam where adult salmon find their first barrier on the Columbia river, is being observed by biologists of the U. S. Bureau of Commercial Fisheries

THE INCREASING NUMBER of dams along routes of adult salmon on their way to spawning grounds have created problems that government fishery biologists are seeking to solve. Among other methods, the U. S. Bureau of Commercial Fisheries is tracking adult fish near dams in the Pacific Northwest by sonic means to observe their behavior in migration.

This tracking equipment was employed at Bonneville Dam, the first barrier encountered by adult salmon in the Columbia River. From observations made in the forebay of the dam, it appeared that the migrants preferred to swim near the shoreline and in water 30 feet deep or less. The fish usually resumed their migration upstream within an hour after release and proceeded at the rate of about 1½ miles per hour. Occasionally, however, a fish was found to swim downstream to the spillway of the dam, a potentially dangerous area during periods of high flows and increased water velocities.

Also, during the Bonneville experiments, there was an indication that daylight movement differed from behavior in darkness. At night, the fish appeared to move slower, mill about more often, and in some cases, return downstream for a considerable distance.

Similar observations were recorded in a large impoundment, a specific area where adult salmon were released after being trapped and transported by tank truck. In migrating through this larger reservoir, the fish seemed to wander more and experience greater difficulty than when passing through a smaller body of water. Here again, they preferred the shorelines and changes in behavior were witnessed, depending on the amount of daylight.

The entire tracking system for following the tagged fish is contained in this small boat

Photo by Bureau of Commercial Fisheries

One of the basic tools of the system used for tracking is a subminiature transducer that sends out sound waves picked up by special receiving apparatus. And is small enough and simple enough to be tagged to a fish. The tag is self-contained, battery-operated, 1⅞ inches long and ⅞ inch in diameter at its widest point. In water, this tag weighs only between 5 and 10 grams, due to displacement. All the component parts (battery power source, electronic circuitry, transistor, and resonating crystal) are enclosed within a plastic shell to which a "hog ring" device is connected for attachment to a large adult salmon. The tag sends out a constant 132 kilocycle signal that can be continuously tracked for over 200 hours at a 500-foot range. Under ideal conditions the signal can be detected at more than 3,000 feet.

The receiving equipment or tracking system is a modified echo-ranging system. A servo-powered homing device aims the echo-ranging system at the tagged fish, and its position is shown as a bright spot of light on a calibrated cathode-ray tube. The depth of the fish can be computed from angular measurement of the ranging beam in the water and the distance of the fish from the equipment. When the equipment is mounted on a boat a tagged fish can be observed closely for extended periods of time and its movements transferred to a chart to show its behavior patterns.

The sonic tag is now undergoing modification to improve its operational characteristics. New engineering techniques and subminiature components are being used to increase the range and life, as well as to reduce the size and weight of the tag. When sufficiently reduced in size, the tag will be used to track movements of smaller fish. Conceivably, this could include some of the larger juvenile migrants moving toward the sea.

Development of this equipment and experience in using it, will continue to contribute more as time goes on to our knowledge of the migratory habits of fish.

The author is a fishing research biologist of the U. S. Bureau of Commercial Fisheries at Seattle, Washington

death in a plane crash, was a principal sponsor of the Point Reyes bill. His intense personal interest in the Point Reyes area, and the unflagging attention which he devoted to securing favorable Congressional action on the Point Reyes bill qualify him as the prime mover of the Point Reyes seashore. In addition, he was a strong advocate of legislation creating Padre Island and Cape Cod seashores, and was generally one of conservation's great friends in Congress.

Attainment of these three seashores is proof that conservation goals can be attained, and should stimulate continued chapter, division and national efforts to preserve those river fronts, lake shores, and ocean beaches which must remain available to meet future public demands for outdoor opportunities.

The trend toward depending upon the modern swimming pool entirely has been forestalled by creating three large seashore areas along our continental seacoasts

hotos by National Park Service
lower right by Philip Hyde from
id in Time: The Point Reyes
ula," published by Sierra club

Drake's Bay Point Reyes National Seashore is just 35 miles from downtown San Francisco and probably looks the same as it did when Sir Francis Drake saw it on his famous voyage in 1579

t, between Corpus Christie and Port Isabel, is an w. It varies in width from one-eighth to three miles

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Growth of Pure Cultures of Marine Phytoplankton in the Presence of Toxicants

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ABSTRACT

Ukeles, Ravenna (U.S. Bureau of Commercial Fisheries, Milford, Conn.). Growth of pure cultures of marine phytoplankton in the presence of toxicants. Appl. Microbiol. **10**:532–537. 1962.—The effects of 17 toxicants on the growth of five species of algae in pure culture were studied. The two species displaying the greatest sensitivity to the action of each of the compounds tested were *Monochrysis lutheri* and *Phaeodactylum tricornutum*, and the most resistant species was *Protococcus*. Of eight different classes of toxicants tested, substituted urea compounds and a mercuric compound were most effective in inhibiting growth of all algal species at the lowest concentrations.

The widespread use of toxic chemicals, as a means of pest control, aroused interest in the effects of these agents on all plants and animals. Since the introduction of 1,1,1,-trichloro-2,2-bis(*p*-chlorophenyl)ethane (DDT) as an insecticide, other highly toxic organic compounds have been synthesized and used in large quantities over land and aquatic areas. The broad effects of these practices on plants, wildlife, livestock, and public health are now recognized (Tarzwell, 1960).

Contamination of estuaries can occur through runoff from treated lands or from the application of herbicides and insecticides to marsh areas adjoining water basins. In addition to this accidental introduction of toxicants into estuarine waters, chemical methods are being developed for the control of predators, competitors, and fouling organisms on commercial shellfish beds. These methods include spreading of chemically treated sand over beds, chemical treatment of cultch, and use of chemically treated baits (Loosanoff, 1960). Data are needed on the effects on phytoplankton of the introduction of these compounds, since the fertility of natural waters and their ability to support fish or shellfish populations depend upon phytoplankton which constitute the base of the marine food chain (Provasoli and Pinter, 1953).

Shellfish hatchery practices being developed at Milford Laboratory include chemical methods for the control of bacterial and fungous infections of lamellibranch larvae (Davis et al., 1954; Guillard, 1959). To evaluate the efficacy of these methods, the tolerance to these chemicals of algal species utilized as foods by larvae should be inve gated. Finally, there is a demand for information chemicals that can destroy nuisance algae in water s plies (Palmer and Maloney, 1955) and aquatic weeds estuarine and fresh-water environments (Maloney, 19

This study was undertaken to provide information the tolerance of marine phytoplankton that are import foods for oyster and clam larvae (Davis and Guilla 1958) to compounds classified as "toxicants" (DeO 1953). These compounds include bactericides, fungici herbicides, and insecticides.

Materials and Methods

The test species included two motile flagellates, *Mo chrysis lutheri* Droop [*Chrysophyceae* (Droop, 1953)] *Dunaliella euchlora* Lerche [*Chlorophyceae* (Lerche, 193 and two nonmotile unicells, *Chlorella* sp. and *Protoco* sp. [*Chlorophyceae* (isolated at Milford)]. The fifth spec *Phaeodactylum tricornutum* Bohlin [*Phaeodactyla* (Lewin, 1958)], has also been classified as a diatom un the name *Nitzschia closterium* Ehrenberg Wm. Smith for *minutissima* (Allen and Nelson, 1910).

The basal medium (autoclaved at a pressure of 15 psi 20 min) used for the culture of algae had the follow composition: KH_2PO_4, 20 mg; thiamine hydrochlori 0.2 mg; biotin, 2 μg; vitamin B_{12}, 2 μg; $NaNO_3$, 150 r ferric sequestrene (13% Fe), 10 mg; NH_4Cl, 50 r $CuSO_4 \cdot 5H_2O$, 0.019 mg; $ZnSO_4 \cdot 7H_2O$, 0.044 mg; CoC $6H_2O$, 0.022 mg; $MnCl_2 \cdot 4H_2O$, 0.360 mg; $Na_2MoO_4 \cdot 2H$ 0.0126 mg; and sea water (salinity 22 to 28 parts thousand) to make 1 liter of solution.

Toxicants were prepared as concentrated or satura stock solutions in sterile sea water. At least 24 hr la serial dilutions in sterile sea water were made, and 1 samples of the appropriate dilution were added to 9 m sterile basal medium. Final concentrations of toxica were calculated on the basis of the per cent of act ingredient in aqueous solution and given as parts million of the pure compound. The compounds test with commercial names, chemical composition, ma facturers, and common usages, are given in Table 1. T formulations and solubility in water, as given by manufacturer or indicated in the literature, are also list

Although, to avoid alteration of the compound, st solutions of toxicants were not sterilized, the high conc

ation of the solutions and the subsequent aseptic handg of media and cultures presumably kept all experiental cultures essentially free of contaminants. Lindane s an exception to this method of preparation. To obtain gh concentrations, this toxicant was added directly to e basal media and sterilized for 10 min.

Cultures were incubated in Pyrex screw-cap test tubes with the plastic cap liners removed. Each tube was inoculated with 0.5 ml of a bacteria-free unialgal stock culture maintained on the enriched sea-water basal medium. The initial number of cells in the test medium was about 150,000 per ml for four species and about

TABLE 1. *Toxicants used in study of marine phytoplankton*

Common name	Chemical name, formulation, and solubility in water	Manufacturer	Common use
	Organic phosphates		
EPP	Tetraethylpyrophosphate; 40% + 60% related organic esters; very soluble in water	Niagara Chemical Division, Middleport, N.Y.	Insecticide
ptorex	*o,o*-Dimethyl-1-hydroxy-2,2,2-trichloroethyl phosphonate; 50% soluble powder; 130,000 ppm	Chemagro, New York, N.Y.	Insecticide
	Phenolics		
rbolic acid	Phenol; very soluble in water	Mallinckrodt Chemical Works, St. Louis, Mo.	Bactericide
wacide A	Sodium orthophenyl phenate·$4H_2O$; 97%; 1,220,000 ppm	Dow Chemical Co., Midland, Mich.	Bactericide
	Oils		
Dichlorobenzene	Orthodichlorobenzene; 130 ppm	Commercial Solvents Corp., Terra Haute, Ind.	Organic solvent
iagara compound 3514	2-Chloro-1-nitropropane; 8,000 ppm	Niagara Chemical Division, Middleport, N.Y.	Experimental compound
	Iodophor		
VP	Polyvinylpyrrolidone-iodine	Antara Chemical Co., New York, N.Y.	Bactericide-fungicide
	Chlorinated hydrocarbons		
DT	1,1,1-Trichloro-2,2-bis(*p*-chlorophenyl)-ethane, wettable powder; 0.0002 ppm (0.2 ppm colloidal solution)	Naugatuck Chemical Division, Naugatuck, Conn.	Insecticide
ndane	γ-1,2,3,4,5,6-Hexachlorocyclohexane; 10 ppm	California Spray-Chemical Corp., Richmond, Calif.	Insecticide
oxaphene	Mixture of polychloro dicyclic terpenes with chlorinated camphene predominate, 60% emulsion concentrate; 1.5 ppm	Hercules Powder Co., Wilmington, Del.	Insecticide
	Carbamates		
ban	Disodium ethylene bis-dithiocarbamate hexahydrate; very soluble in water	Niagara Chemical Division, Middleport, N.Y.	Fungicide
vin	1-Naphthyl-*N*-methylcarbamate; 95%; 1,000 ppm	Union Carbide Chemicals Co., New York, N.Y.	Insecticide
	Organic mercury		
gnasan	Ethyl mercury phosphate; 6.25%; very soluble in water	E. I. du Pont de Nemours and Co., Inc., Wilmington, Del.	Bactericide-fungicide
	Urea derivatives		
uron	3-Phenyl-1,1-dimethyl urea; 2,900 ppm	E. I. du Pont de Nemours and Co., Inc., Wilmington, Del.	Herbicide
uron	3-(*p*-Chlorophenyl)-1,1-dimethyl urea; 230 ppm	E. I. du Pont de Nemours and Co., Inc., Wilmington, Del.	Herbicide
uron	3-(3,4-Dichlorophenyl)-1,1-dimethyl urea; 42 ppm	E. I. du Pont de Nemours and Co., Inc., Wilmington, Del.	Herbicide
uron	1-*n*-Butyl-3-(3,4-dichlorophenyl)-1-methyl urea; 4.8 ppm	E. I. du Pont de Nemours and Co., Inc., Wilmington, Del.	Herbicide

250,000 per ml for *P. tricornutum*. Loosely capped culture tubes were incubated in a culture room with a continuous light intensity of about 500 ft-c and a temperature of 20.5 ± 1 C. After an incubation period of 10 days, during which tubes were frequently rotated, growth in experimental cultures was visually compared to that of controls and recorded on a scale of 0 to +. After finding the range of concentrations that had no effect and those that appeared to be lethal, sublethal toxicant concentrations were investigated. In these experiments, optical density measurements of growth were made with a Beckman spectrophotometer at a wavelength of 530 mμ. To test the presence of viable organisms where there was visible growth, a 1-ml sample was transferred to the b medium with no added toxicant and observed for gro after 10 to 14 days.

Results

The growth response in the presence of toxicants is gi for each species in Table 2. The results are expressed

TABLE 2. *Effect of toxicants on growth of phytoplankton*[a]

Toxicant	Concn	*Protococcus* sp.	*Chlorella* sp.	*Dunaliella euchlora*	*Phaeodactylum tricornutum*	*Monochrysis lutheri*
	ppm					
Dipterex	10	0.75	0.84	0.59	1.00	1.00
	50	0.65	0.70	0.54	0.85	0.55
	100	0.54	0.68	0.42	0.39	0.00
	500	0.29	0.00	0.00	0.00	0.00
	1,000	0.00	0.00	0.00	0.00	0.00
TEPP	100	0.62	0.65	0.90	0.58	0.83
	300	0.17	0.27	0.49	0.25	0.38
	500	0.00[b]	0.00[b]	0.00	0.00	0.00
	1,000	0.00[b]	0.00	0.00	0.00	0.00
Phenol	10	0.77	0.83	0.86	1.20	0.78
	100	0.71	0.84	0.51	0.00[b]	0.00[b]
	300	0.59	0.63	0.47	0.00[b]	0.00[b]
	500	0.00	0.00	0.00	0.00	0.00
Dowacide A	10	0.90	0.90	0.70	0.82	0.68
	25	0.74	0.90	0.81	0.48	0.22
	50	0.76	0.74	0.52	0.22	0.00
	100	0.00[b]	0.00[b]	0.00[b]	0.00	0.00
	1,000	0.00	0.00	0.00	0.00	0.00
Orthodichloro-benzene	1.3	0.71	0.82	0.71	0.74	1.00
	7.6	0.80	0.95	0.90	0.80	0.65
	13	0.00[b]	0.00[b]	0.00[b]	0.00[b]	0.00[b]
	130	0.00	0.00	0.00	0.00	0.00
Chloronitro-propane	0.8	0.94	0.90	0.81	1.00	1.00
	8	0.72	0.25	0.83	0.72	0.69
	80	0.00	0.00	0.00	0.00	0.00
PVP-iodine	10	0.87	0.90	1.00	1.00	0.96
	20	0.88	0.65	1.00	0.90	0.71
	50	0.80	0.30	0.00[b]	0.00[b]	0.61
	100	0.59	0.27	0.00	0.00[b]	0.00
Sevin	0.1	0.80	0.90	0.90	0.00[b]	0.87
	1	0.74	0.80	0.65	0.00[b]	0.00[b]
	10	0.00[b]	0.00	0.00[b]	0.00	0.00
	100	0.00	0.00	0.00	0.00	0.00
Nabam	0.1	0.93	0.80	0.27	0.82	0.
	1	0.53	0.63	0.00	0.00[b]	0.
	10	0.00	0.00	0.00	0.00	0.
Lindane	1	1.40	0.88	1.00	1.00	0.
	2.5	1.40	0.73	1.00	0.82	1.
	5	0.75	0.57	1.00	0.30	1.
	7.5	0.75	0.36	0.73	0.00[b]	0.
	9	1.00	0.33	0.60	0.00[b]	0.
Toxa-phene	0.01	1.00	0.70	0.90	0.54	0.
	0.04	0.77	0.70	0.55	0.00[b]	0.
	0.07	0.80	0.00[b]	0.53	0.00[b]	0.
	0.15	0.00	0.00	0.00	0.00	0.
DDT	0.02	1.00	1.00	0.83	1.00	0.
	0.04	1.00	1.00	0.85	0.91	0.
	0.60[d]	0.50	1.00	0.74	0.91	0.
Lignasan	0.0006	0.86	0.78	0.64	0.55	1.
	0.006	0.00	0.00	0.31	0.17	0.
	0.06	0.00	0.00	0.00	0.00	0.
Fenuron	0.03	0.93	0.95	1.00	1.00	1.
	0.29	0.72	0.82	0.46	0.82	0.
	2.90	0.33	0.00[b]	0.00[b]	0.00[b]	0.
	29	0.00	0.00	0.00	0.00	0.
Neburon	0.04	0.41	0.31	0.47	0.10	0.
	0.20	0.00[b]	0.00	0.00[b]	0.00[b]	0.
	0.40	0.00	0.00	0.00	0.00	0.
Monuron	0.001	0.90	0.30	1.00	0.65	0.
	0.02	0.00[b]	0.00[b]	0.00[b]	0.00[b]	0.
	0.20	0.00	0.00	0.00	0.00	0.
Diuron	0.00002	0.52	1.00	0.80	0.83	0.
	0.0004	0.22	0.62	0.44	0.79	0.
	0.004	0.00	0.34	0.00[b]	0.00	0.
	0.04	0.00	0.00[b]	0.00[b]	0.00	0.
	0.40	0.00	0.00	0.00	0.00	0.

[a] The optical density of the control cultures was as follows: *Protococcus* sp., 0.407, *Chlorella* sp., 0.570, *Dunaliella euchlora*, 0. *Phaeodactylum tricornutum*, 0.600, *Monochrysis lutheri*, 0.314. Growth expressed as the ratio of optical density with toxicant/opt density with no toxicant.

[b] No growth but organisms were viable.

[c] Lower concentrations gave the following results: 0.0015 ppm, 0.00; 0.00015 ppm, 0.00; 0.000015 ppm, 0.78.

[d] A concentration of 1.00 ppm as an acetone solution did not inhibit growth of any organism.

[e] Lower concentrations gave the following results: 0.004 ppm, 0.00; 0.0004 ppm, 0.62.

he ratio of optical density of growth in the presence of oxicants to optical density in the basal medium with no dded toxicants. Results are presented for both resistant nd sensitive species, illustrating the range of concentraons (i) that did not significantly inhibit growth; (ii) hat appreciably decreased the rate of growth or inhibited ell division entirely, although viable organisms were pres-nt; and (iii) that appeared to be lethal since there was no rowth, and organisms did not appear to be viable under he conditions of the test.

The organic phosphates, *o,o*-1-hydroxy-2,2,2-trichloroethyl phosphonate (Dipterex) and tetraethylpyrophosphate (TEPP), were the toxicants tolerated in the highest concentrations by all species. Dipterex at 50 ppm caused less than 50% inhibition of each species, and the concentration of 100 ppm was lethal to only one species. There was also no appreciable inhibition of growth with TEPP at 100 ppm. Growth of all species was inhibited by 500 ppm of either compound, but the most resistant species, *Protococcus*, was still viable in 500 ppm of each compound, and *Chlorella* was viable in 500 ppm of TEPP.

The resistance to phenolic compounds was also high. Although phenol at 300 ppm, and Dowacide A at 50 ppm, caused some reduction in the rate of growth of three chlorophytes, only growth of *P. tricornutum* and *M. lutheri* was inhibited at these concentrations. Phenol was lethal at 500 ppm to all species, and Dowacide A caused inhibition of growth of the three chlorophytes and death of the two less resistant species at 100 ppm.

Orthodichlorobenzene and chloronitropropane had no significant effect on growth at 8 ppm, except that *Chlorella* seemed sensitive to this concentration of chloronitropropane. Lethal or inhibitory concentrations were reached at about ten times this amount. The iodophor compound polyvinylpyrrolidone-iodine also seemed to have little effect at a concentration of 10 ppm, but became toxic as concentrations approached 100 ppm.

The carbamate compounds 1-naphthyl-*N*-methylcarbamate (Sevin) and nabam may be considered next in general order of increasing toxicity. Although 1 ppm of Sevin did not seriously influence the growth of the three most resistant species, growth of *P. tricornutum* and *M. lutheri* was completely suppressed. Concentrations of 10 ppm were lethal to three species. Nabam allowed growth of two of the resistant species at 1 ppm, but 10 ppm appeared lethal to all organisms.

The response to the chlorinated hydrocarbons varied within the group. Lindane was inhibitory to the two most sensitive species at 7.5 ppm, but other species were little affected, and even the two most sensitive species were viable.

1,1,1 Trichloro 2,2 bis(*p* chlorophenyl) ethane (DDT) in colloidal solution at 0.6 ppm did not affect growth, with the exception of *M. lutheri*. There was some inhibition of growth of *M. lutheri*, but this may not be of significance since a solution of DDT in acetone at 1 ppm was not lethal. Toxaphene, a mixture of chlorinated camphenes, was the most toxic of this group of chlorinated hydrocarbons. A concentration of 0.01 ppm of toxaphene was tolerated by four species but 0.15 ppm was lethal to all organisms. *M. lutheri* showed a striking sensitivity to this compound and as little as 0.001 ppm was lethal.

The compounds with the greatest degree of toxicity were Lignasan, and the substituted ureas. Lignasan was lethal to all species at 0.06 ppm, and 0.0006 ppm was the only concentration tested that did not cause drastic inhibition of growth. The least toxic of the substituted urea compounds, fenuron, was tolerated at 0.29 ppm, but 1-*n*-butyl-3-(3,4-dichlorophenyl)-1-methylurea (neburon) at 0.04 ppm caused more than 50% reduction in growth of three species and had a still more drastic effect on the two most sensitive species. 3-(3,4-Dichlorophenyl)-1,1-diphenylurea (diuron) and 3-(*p*-chlorophenyl)-1,1-dimethylurea (monuron) were the most toxic compounds in this group. Monuron had little effect at 0.001 ppm, and diuron at 0.0004 ppm, although even the latter was lethal to *M. lutheri*.

There were some fairly consistent differences in the sensitivity of the five species of phytoplankton to toxicants. The naked, free-swimming chrysomonad, *M. lutheri*, was in every case most susceptible to the action of the toxicants and, in the case of toxaphene, the difference was very marked. The other brown pigmented species, *P. tricornutum*, often showed tolerances similar to *M. lutheri*. In contrast, the green pigmented chlorophytes, both motile and nonmotile, were always the most resistant and, of this group, *Protococcus* was usually the most resistant.

Even the most sensitive species, *M. lutheri*, could withstand exposure to sublethal doses of a toxicant for long periods of time. Cultures of *M. lutheri* that were incubated for as long as 6 months in 1 ppm Sevin, 1 ppm lindane, and 0.0006 ppm Lignasan were still capable of reproducing when transferred to the basal media without toxicant.

Microscopic observations showed concentrations of toxicants that were lethal frequently caused cell lysis and, in some cases, resulted in morphological abnormalities of the cell.

Discussion

For practical purposes, bio-assays of toxicants are valuable in indicating concentrations that are harmful and concentrations that appear to have no effect and, therefore, may be considered "safe." Experiments with pure cultures under defined conditions yield specific information important in the understanding and managing of ecological situations. However, field studies should be conducted before laboratory-determined "safe" concentrations can be extrapolated for use in natural environments. It seems reasonable to assume that, under certain ecological conditions particularly favorable to the growth of algae, or where the ambient concentrations of toxicant fluctuate widely, some phytoplankton species may survive in an otherwise inhibitory or lethal concentration of toxicant. For example, copper ore, at concentrations that ap-

peared promising in laboratory experiments (Marvin, Lanford, and Wheeler, 1961), was not useful in the treatment of natural waters to suppress harmful flagellate blooms. On the other hand, even sublethal concentrations of toxic chemicals in isolated pools may drastically alter natural populations.

Some toxicants used for predator control in shellfish hatcheries may be "safe" at higher concentrations than under natural conditions. In hatchery procedures, plankton food obtained from another source is being continuously supplied to lamellibranch cultures. In this case, where massive concentrations are being utilized as foods, compounds used for the control of predators may be "safe" for feeding at concentrations that cause inhibition of algal growth. Polyvinylpyrrolidone-iodine, for example, has been found useful in hatchery trays to control predators at 100 and 250 ppm, yet these concentrations are lethal to some algal species and inhibit growth of others. In nature, however, blooms are important as a source of food and because of this an inhibition of phytoplankton blooms and long-term effects on the natural flora and fauna must be considered. Although many toxicants have a low water solubility, the introduction of even traces of certain metals, toxic ions, and organic molecules may influence the basic ecology of a particular environmental niche and result in a change in the complex relationship between endogenous phytoplankton populations, phytoplankton blooms, and phytoplankton feeders (Provasoli, 1958).

It must be emphasized that the effects of environmental factors on the stability and potency of toxicants present a problem in the evaluation and correlation of results. For example, DDT is virtually insoluble in water, and its effectiveness varies with the type of solvent used. Although, in general, the toxicity to crops of DDT in aqueous solution is low, an oil solution may be phytotoxic (Brown, 1951). DDT is also affected by the type of experimental container, being more toxic in a glass than an enamel, aluminum, or plastic vessel (Cole, 1961). Dipterex and TEPP hydrolyze in solution within a few days (Albert, 1960), and lindane decays 70% in sea water after 30 days (Werner and Waldichuk, 1961). In our experiments, it has been found that a freshly prepared solution of nabam is more toxic than an aged solution. The instability of toxicants may be advantageous in certain applications and may account for the resistance to the action of the organic phosphates. Resistance to the action of a toxicant may also be due to permeability barriers, and, therefore, modifications of environmental factors influencing permeability could produce different results.

The commercial use of a toxicant is based on selective toxicity, i.e., the chemical must be more toxic to pest species than to the valuable species. This selectivity of toxicants may be judiciously employed in the commercial application of toxicants to remove predators so that the desirable forms of phytoplankton are still maintained in aquatic environments; or, conversely, it would seem possible to use certain toxicants to remove undesira algal species and leave other populations unharmed. example, organic phosphorus and chlorinated hydro bon compounds have been used to control an arthro invasion of an open-tank culture of *Chlorella* and *Chla domonas* (Loosanoff, Hanks, and Ganaros, 1957). It found that 1 ppm of Dipterex, lindane, DDT, or TEPP not affect the culture, although copepod invaders w sucessfully eliminated. Similarly, compounds of Ligna or monuron may be used in very low concentrations to areas of troublesome algal species. In fact, it has been ported that Lignasan was used to clear fish ponds of toxic flagellate *Prymnesium parvum* (Sarig and Lah 1961). Monuron has also been used successfully to er cate filamentous algae from a fresh-water pond, with adverse effects on fish (Maloney, 1958). These two cla of compounds may also be useful as algicides in ma environments.

It is important to examine the basis of the selective tion of various toxicants so that a logical use of th chemicals may be pursued with a minimal amount damaging side effects. The effect to TEPP has been tra to an anticholinesterase action (Brown, 1951), and, a nerve poison, it follows that its phytotoxicity should low. Even 100 ppm of TEPP had no effect on phytoplankton tested. Dipterex, another organic ph phorus compound, at 100 ppm was lethal to only the m sensitive organism.

The chlorinated hydrocarbons, lindane and DDT, also reported to have a nerve action and stimulate ne fibers to convulsions (Albert, 1960). Although 0.05 ppm lindane is a 100% lethal dose for *Anopheles* larvae (Spect 1956) and 0.2 ppm killed crabs (Loosanoff et al., *unp lished data*), 5 ppm had no effect on any of the five spe of phytoplankton tested. It has previously been repor that protozoa are resistant to the action of DDT (Richa and Cutkomp, 1946), and DDT has also been found n toxic to six species of fresh-water algae at 2 ppm (Pal and Maloney, 1955).

Certain toxicants act through chromosomal effe and it is to be expected that these compounds would more general protoplasmic poisons. Lignasan indu multipolar spindles in some plants (Spector, 1956), carbamate compounds have also been reported to suppr cytoplasmic division (Spector, 1956), which may acco for the low "safe" concentrations of these compounds.

The asymmetric substituted urea compounds are portant herbicides and there is recent evidence that th compounds act by interfering with the utilization of li and CO_2 in the photosynthetic process (Craft, 1961). W the group of substituted urea compounds, the parent rivative, fenuron, a phenyl urea, was the least toxic of series, and the chlorinated phenyl ureas were most to

Determination of the capacity of algae to develop str that are resistant to the action of some of these toxi compounds would be of interest. Because of their r

wth and ease of handling under controlled conditions, otozoan organisms have been a valuable assay tool. The al species used here may be suitable for bio-assays of tain toxicants, particularly herbicides.

ACKNOWLEDGMENT

The author expresses appreciation to Rita Riccio for ting the manuscript.

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CONTRIBUTION
No. 151
Galveston Biological Laboratory
U. S. Bureau of Commercial Fisheries

A Device for Feeding Brine Shrimp to Fishes

Because of its ready availability and apparent acceptance as food by many species of fish, the brine shrimp (*Artemia salina*) is commonly used to feed small fishes held under laboratory conditions. Brine shrimp eggs are usually hatched in shallow pans, and the resulting nauplii are periodically fed to the fish. Since most fishes forage constantly under natural conditions, a continuous supply of food is probably preferable to periodic feedings. Based on the brine shrimp's attraction to light, a "feeder" was developed to provide a continuous trickle of nauplii into tanks containing experimental fish.

The feeder, shown diagrammatically in Figure 1, is a vessel constructed of polyvinyl chloride (PVC) and polyethylene, both inert materials. It is opaque except for the open stem at one end. In operation, the vessel is filled with sea water to approximately 1 inch from the top. The height of the vessel is adjusted until the water level is about equal to that in the adjacent fish tank. A bridge is established between the feeder and the fish tank by means of a glass siphon attached to the stem on the one end, and immersed in the fish tank on the other.

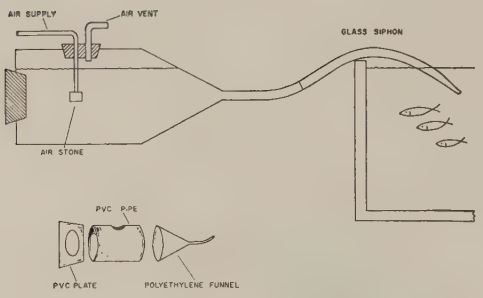

FIGURE 1.—Details of construction and operation of brine shrimp feeder.

Eggs are placed in the feeder and approximately 24 hours later begin to hatch. If a light source is placed 2 or 3 feet from the end of the siphon and directly in line with it, the emergent nauplii, attracted by the light, will move through the siphon and into the fish tank.

To improve hatching conditions, the water in the feeder is aerated gently. Violent aeration may force eggs and eggshells through the siphon and into the fish tank. To eliminate the possibility of fish entering the feeder through the siphon, the end of the siphon can be drawn out to an appropriate diameter, or it can be covered with coarse-mesh screening. If it is desirable to minimize the mixing of the water in the fish tank with that in the feeder, the two water levels should be carefully equalized before the siphon is established. This is particularly important when freshwater fishes are involved, since brine shrimp eggs must be hatched in salt water.

Details of construction are illustrated in Figure 1. The dimensions are not critical, and can be modified to meet particular requirements. For a feeder with a capacity of approximately 1 gallon, a PVC plate 6 by 6 inches and ¼ inch thick is cemented to one end of a PVC pipe 6 inches long with inside diameter 6 inches, outside diameter 6¼ inches. Epoxy putty (Bradco Plastics Inc., Lake Jackson, Texas) is used as a cementing agent. A hole 3½ inches in diameter, sufficiently large to accommodate a No. 15 rubber stopper, is drilled in the plate to permit access for cleaning the feeder. A 160-millimeter polyethylene funnel is cemented to the other end of the pipe. The stem of the funnel is bent upwards by immersion in boiling water, curving to the desired shape, and cooling under running tap water. The funnel is wrapped with black tape up to the bend in the stem so that the only light entering the vessel will come through the siphon. The glass siphon is attached to the funnel stem by a short piece of tygon tubing. A short siphon with a gradual bend is desirable. A sharp bend, especially near the tip of the siphon, will impede the movement of brine shrimp into the fish tank.

Water and eggs are added to the feeder through an opening at the top. The hole, 2½ inches in diameter, accommodates a No. 13 rubber stopper through which two glass elbows pass. One is part of the air supply line, and attached to it is a small airstone; the other is used as an air vent and extends just below the bottom of the stopper. The two elbows are wrapped with black tape to prevent the entry of light from the top.

In feeding 25 to 30 juvenile fish in a 20-gallon aquarium, we have obtained satisfactory results by adding to the feeder 1 teaspoon of eggs per day for 5 days. On the 7th day the feeder is cleaned and restocked with new water and eggs. Because of the time required for hatching, nauplii will not be available for approximately 24 hours after the feeder is restocked. During this period provision should be made for supplemental feeding either with brine shrimp hatched in the conventional manner, or with dry foods.

To demonstrate the utility of this method of feeding fish held in the laboratory, two feeders were established in the manner described above except that fish were not stocked in the aquaria. The nauplii that hatched and moved through the siphons into the aquaria were collected each day for 5 days. Their settled volumes ranged daily from 4 to 5 milliliters except on the 5th day when one aquarium yielded slightly less than 3 milliliters.

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Ignitron-Pulsed Electric Fence

GUIDES MIGRATING SALMON

By CHARLES D. VOLZ, U.S. Fish and Wildlife, Sand Point Naval Air Station, Seattle 15, Washington.

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Ignitron-Pulsed Electric Fence

GUIDES MIGRATING SALMON

Direct-current pulses fed to immersed electrodes keep fish out of hydroelectr turbines, help them reach their breeding grounds without mishap. Sequenti ignitron triggering gives pulse-sweeping effect.

By CHARLES D. VOLZ, U.S. Fish and Wildlife, Sand Point Naval Air Station, Seattle 15, Washington.

FIG. 1—Electric fence, powered by 360 Kw d-c generator, is on Lake Tapps, near Auburn, Washington

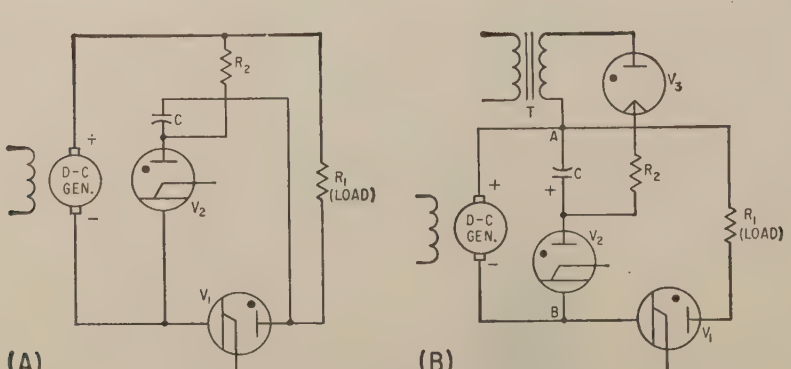


FIG. 2—Ignitron V_1 (A) passes pulses to fish fence, second ignitron V_2 turns V_1 off. In (B), precharged capacitor C is connected by V_2 across the terminals to reverse ignitron V_1 polarity and terminate the pulse

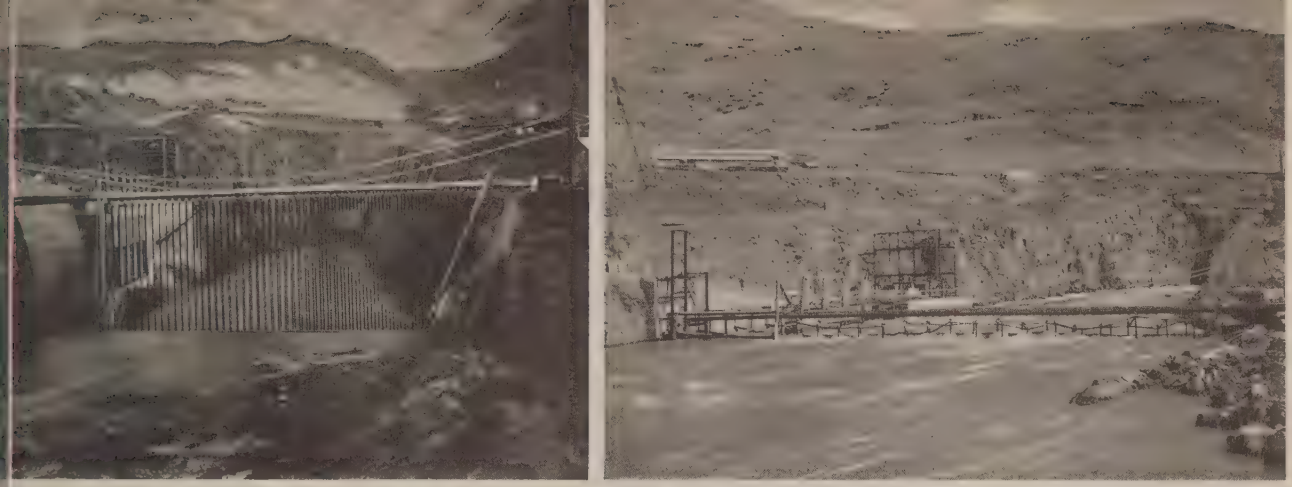
THE U. S. DEPARTMENT OF FISHERI has taken a cue from the catt men and is now using an unde water electric fence to shepherd m grating and spawning salmon in the right traffic lanes for their jou ney to and from the ocean.

Construction projects for dar and hydroelectric power station fr quently bypass the water flow using diversionary tunnels; sin the water velocity in these tunne is high, salmon returning to the breeding grounds cannot swi against the current. In such case the salmon are diverted to fis traps, where they are caught a put into fish tanks for transport tion to a calmer region upstrea

Using d-c pulses,[1,2,3,4] electric fi screens are successful in guidi fish into fish traps, and at t Brownlee dam site on the Sna River between Oregon and Ida an electric fish fence about 105 fe long and 40 feet high divert 16,000 salmon and steelhead tro during a period of several month

An improved model of the equi ment has been built for studies salmon fingerlings at Lake Tapp an artificial impoundment ne Sumner, Washington. An outl from the lake leads to the inta for a hydro-electric generati plant. This arrangement, Fig. uses a W shaped array using t traps and has given encouragi results over a two-year operati period.

The pulse generator uses a pa of high-current ignitron tubes, o



Electric fence (left) under construction at Brownlee dam site. Fish traps are seen through opening on left. Fence in use (right) prevents fish fighting upstream against current in diversionary tunnel, directional electric field urges them into fish traps where they are caught and transported past the diversion

to turn-on the pulse, the second one to turn the pulse off. A basic circuit is Fig. 2A while Fig. 2B shows an elementary version of the actual circuit. In Fig. 2A tube V_1 is turned on by an input signal to its grid, so applying the pulse to the underwater electrodes. To turn the pulse off, tube V_2 is triggered and while the capacitor C is charging, tube V_2 effectively parallels V_1. By using a turnoff tube with a lower arc-drop than the turnon tube the plate potential of V_1 is depressed below its conduction level by the low arc-drop of V_2, hence is extinguished.

In the actual circuit, Fig. 2B, commutating capacitor C is connected to the generator bus rather than to the anode of the load tube V_1. This gives a better pulse shape with sharper cutoff, and moreover allows a number of load sections each powered by its own ignitron, to be controlled by one commutating capacitor and turnoff tube. An auxiliary power source is needed in Fig. 2B to charge the commutating capacitor.

Operation of the pulse generator of Fig. 2B is as follows. Capacitor C is charged by its auxiliary power source to approximately the same voltage as the generator output. Control tube V_1 fires (time t_1) and the load current builds up with a time constant determined by armature inductance and circuit resistances, Fig. 3A. The generator voltage drops momentarily then follows Fig. 3B for the duration of its cycle.

To end the pulse, turnoff tube V_2 is fired and connects the commutating capacitor directly across the generator output. Since the commutating capacitor voltage cannot change instantaneously (there is a finite time-constant involved) the voltage at the positive bus is forced negative and in doing so, cuts off the control tube, V_1.

Load current when V_1 goes off, is diverted through V_2, which discharges through the armature. As it does so the voltage across the busses rises sinusoidally (time t_3) to a high positive value owing to armature inductance. If the bus voltage remains initially negative sufficiently long for control tube V_1 to become deionized, this tube will remain off when the bus voltage returns to its normal level and will be readied for the next triggering input.

The voltage across the generator busses may be approximated for the interval t_2 to t_3 by

$$V(t) = E_g + \sqrt{\frac{L}{C}} \times i(0) \times \sin \frac{t}{\sqrt{LC}} - (E_g - E_c) \times \cos \frac{t}{\sqrt{LC}}$$

where E_g is the generator voltage at t_2, $t = 0$, E_c is the capacitor voltage less the tube arc drop, i (0) is the load current at t_2 ($t = 0$), L is the armature inductance and C is the capacitance of the commutating capacitor.

Armature resistance has been assumed much smaller than armature inductance, and inductance is assumed constant. Then

$$\text{at } t_2, \quad t = 0, \quad V(t)1 = E_c$$

$$\text{at } t_3, \quad t = \pi\sqrt{LC}, \quad (t) = 2E_g - E_c$$

At midpoint of t_2 and t_3,

$$t = \frac{\pi}{2}\sqrt{LC}, \quad V(t) = E_g + \sqrt{\frac{L}{C}} \times i(0)$$

The interval available for deionization is represented by the "delta" symbol in Fig 3. This interval is determined by the value of t for $V(t) = 0$. The sine term is zero for $t = 0$ and $t = \pi\sqrt{LC}$ and maximum at

$$t = \frac{\pi}{2}\sqrt{LC}.$$

Figure 4 shows part of the control system. A special feature of the control arrangement is the provision for connecting up the 5 pairs of load switching ignitrons to the electrodes so that pulses are applied sequentially to bunches of electrodes, rather than to all of them simultaneously. The resulting effect is to give a moving pattern of electric charges in the same way that lights around a movie house provide a directional pattern of movements.

The off or commutating circuit is shown in detail in Fig. 5A. Positions of the capacitor and ignitron are the reverse of those shown in Fig. 2B to put the charging thyratron cathodes at generator negative. The diode charging rectifier of Fig. 2B is replaced by full-wave connected thyratrons, which are fired by a delayed gate so that

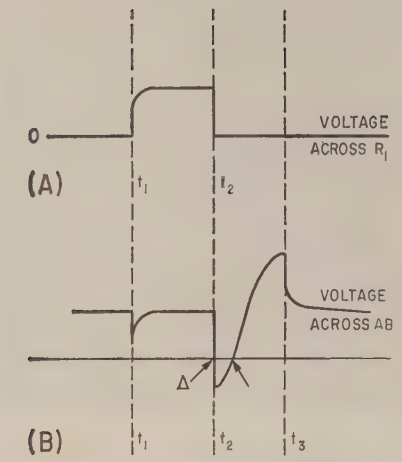


FIG. 3—Upper waveform shows pulse applied to electric fence; lower waveform shows generator terminal voltage

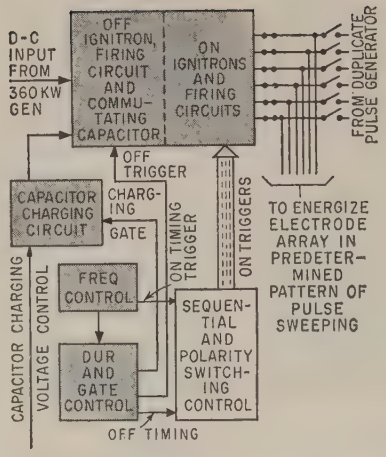

D-C INPUT FROM 360KW GEN
OFF IGNITRON, FIRING CIRCUIT AND COMMUTATING CAPACITOR
ON IGNITRONS AND FIRING CIRCUITS
FROM DUPLICATE PULSE GENERATOR
OFF TRIGGER
CAPACITOR CHARGING CIRCUIT
CHARGING GATE
ON TIMING TRIGGER
ON TRIGGERS
TO ENERGIZE ELECTRODE ARRAY IN PREDETERMINED PATTERN OF PULSE SWEEPING
FREQ CONTROL
SEQUENTIAL AND POLARITY SWITCHING CONTROL
DUR AND GATE CONTROL
CAPACITOR CHARGING VOLTAGE CONTROL
OFF TIMING

FIG. 4—Control equipment uses five pairs of load-control ignitrons to pulse sections of the electrode array in a sequence to steer the fish

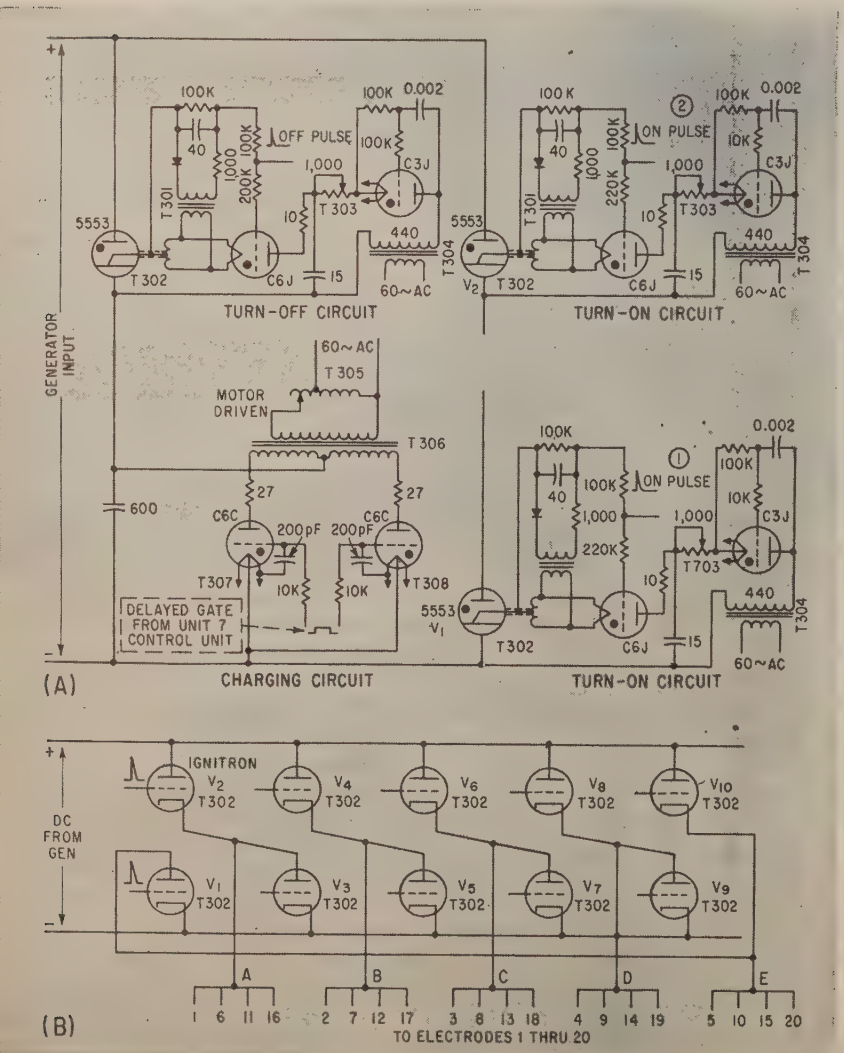


FIG. 5—Single turnoff ignitron terminates the pulse period of whichever load ignitrons are conducting (A). One arrangement of connecting the five pairs of load thyratrons to 20 immersed electrodes to give pulse sweeping effect as the ignitrons are sequentially triggered (B)

they do not fire while the commutating ignitron is conducting.

The five pairs of on or load ignitrons can be interconnected by jumpers in any desired fashion and fired in any sequence or combination. Three of the eleven ignitor firing circuits are shown in detail; all eleven are identical. Capacitor firing is used because of the d-c source and the range of frequency used. The C3J thyratron has a phase-advance network in the grid circuit which causes it to fire very early in the first positive half-cycle of plate voltage, eliminating the transients caused by irregular firing of diode rectifiers.

The polarity and sequential switching circuits use plug-in units, including cathode followers, inverters, gates, multivibrators and pulse amplifiers. These may be interconnected in various ways to produce different firing sequences; for example, the simplest produces a simple sequence firing in which one pair of ignitrons is fired at a time as shown in Fig. 5B.

Four years of operation of this type of equipment has produced highly encouraging results, as an overall diverting effectiveness of at least 90 percent is indicated. It is hoped that within a few years a simple, practical system of fish control and diversion, utilizing electrical techniques, may be developed, which will make a significant contribution to the management of the salmon fishery.

The author wishes to acknowledge the valuable cooperation given by the Idaho Power Company at Brownlee Dam and by the Puget Sound Power and Light Company at Lake Tapps. Charles C. Gillespie is responsible for the mechanical and much of the electrical design of the Lake Tapps equipment, including the automatic overload protection and standby changeover.

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FISHERY OCEANOGRAPHY IN THE TROPICAL ATLANTIC

ROBERT C. WILSON

Bureau of Commercial Fisheries, Biological Laboratory, Washington, D. C.

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FISHERY OCEANOGRAPHY IN THE TROPICAL ATLANTIC

ROBERT C. WILSON

Bureau of Commercial Fisheries, Biological Laboratory, Washington, D. C.

The announced title of my talk is somewhat misleading. While there has been some oceanographic research in the tropical Atlantic, I do not propose to give a history of it. My intention is, within the time allotted to this presentation, to discuss the background of a research program planned for the tropical Atlantic, together with its reasons for being, and its direction and character.

As many of you know, there is a growing tuna fishery in the tropical Atlantic, pursued by Japanese longline vessels, by French and Spanish live bait vessels, and by a few American tuna clippers. The most significant development is by the Japanese. In Fig. 1 may be seen the growth of the fishery in terms of vessels participating. In Fig. 2 the main Japanese longline fishing grounds during 1960 are depicted. In Fig. 3 is shown the Japanese catch of yellowfin tuna, with the principal species plotted against the fishing effort in boat months. It would ap-

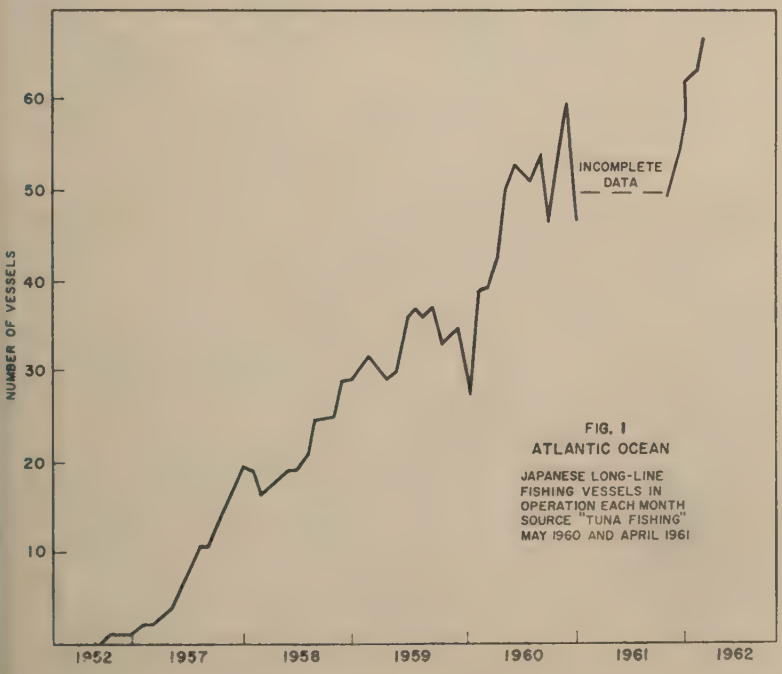


FIG. 1
ATLANTIC OCEAN
JAPANESE LONG-LINE FISHING VESSELS IN OPERATION EACH MONTH SOURCE "TUNA FISHING" MAY 1960 AND APRIL 1961

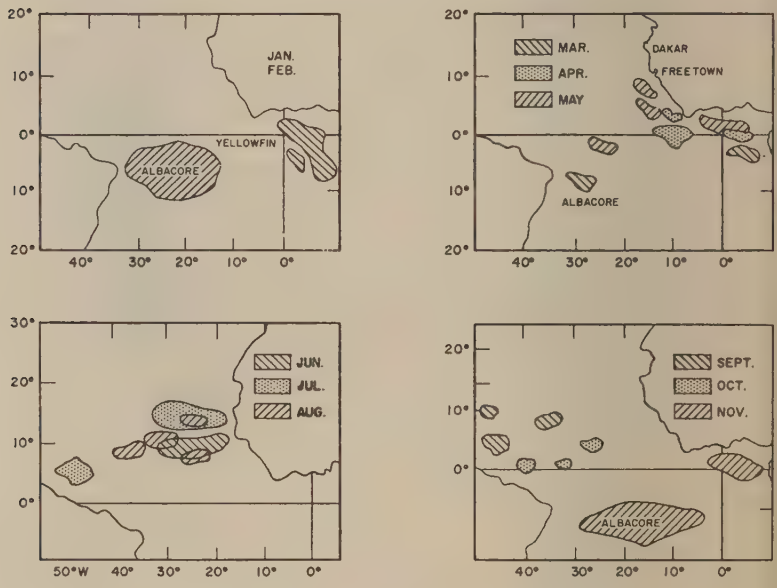


FIG. 2
MAIN JAPANESE LONG-LINE FISHING GROUNDS IN 1960

pear that further increases in fishing effort could result in a commensurate increase in catch.

In addition, there are a number of trawlers of many nations taking demersal and midwater fishes; the Russian fleet is the most impressive segment of this fishery. The interest of both African and non-African nations in the fisheries of this region is an expanding one, with announcements of plans and new developments being frequent items in the flow of news concerning fisheries.

There are two important reasons for this interest, first because the eastern tropical Atlantic appears to possess valuable fishery resources, and secondly, because the 80 million people in the humid tropical area about the Gulf of Guinea lack, to a crippling degree, protein in their diet. It is, unfortunately, a characteristic of the humid tropics that while carbohydrate foods can be produced there in abundance, protein foods cannot. There are a variety of reasons for this, among which the prevalence of diseases in domestic animals is an important one in Africa. While the application of modern agricultural science could do much to solve this problem, it would be a time consuming approach because of the research necessary to develop required answers and be-

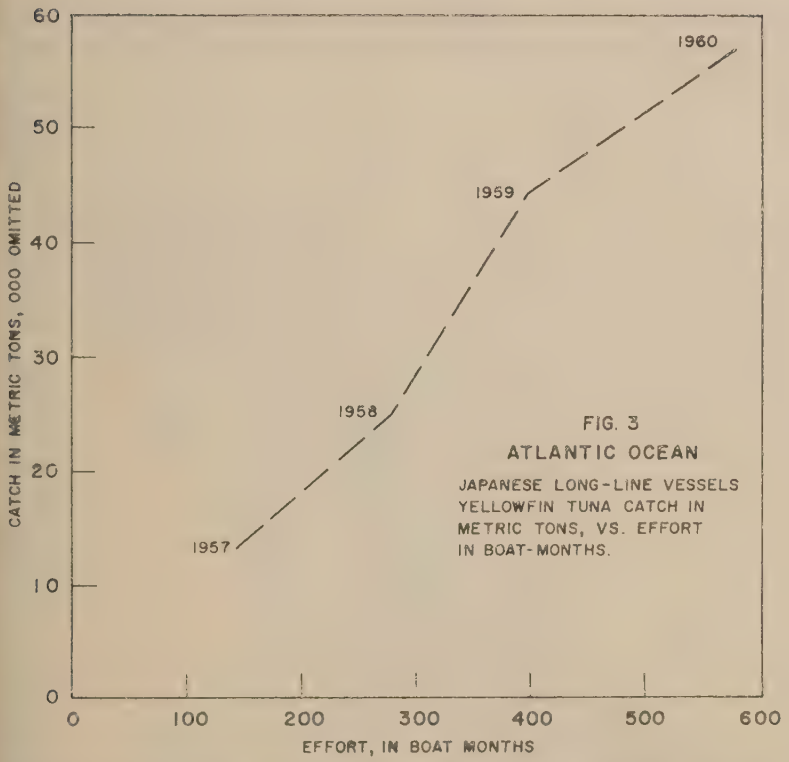


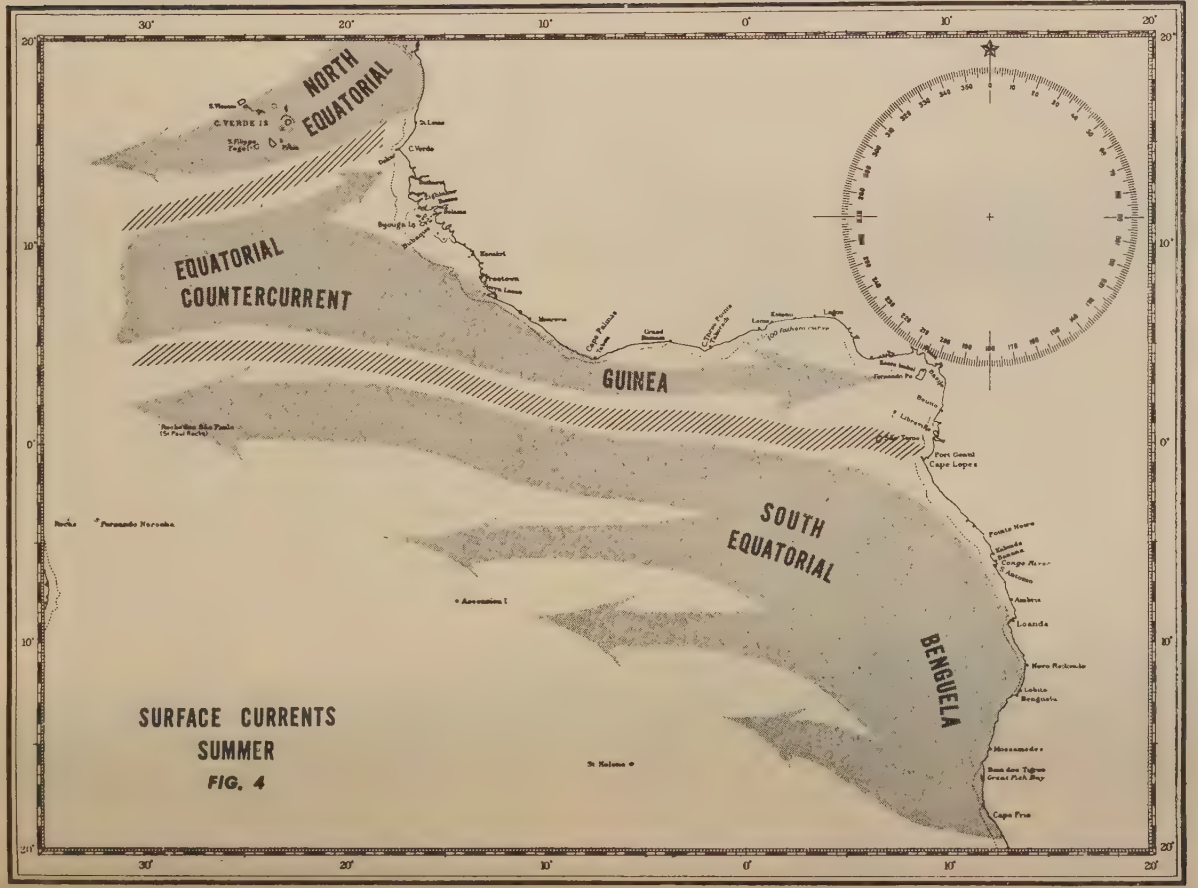
FIG. 3
ATLANTIC OCEAN
JAPANESE LONG-LINE VESSELS
YELLOWFIN TUNA CATCH IN
METRIC TONS, VS. EFFORT
IN BOAT-MONTHS.

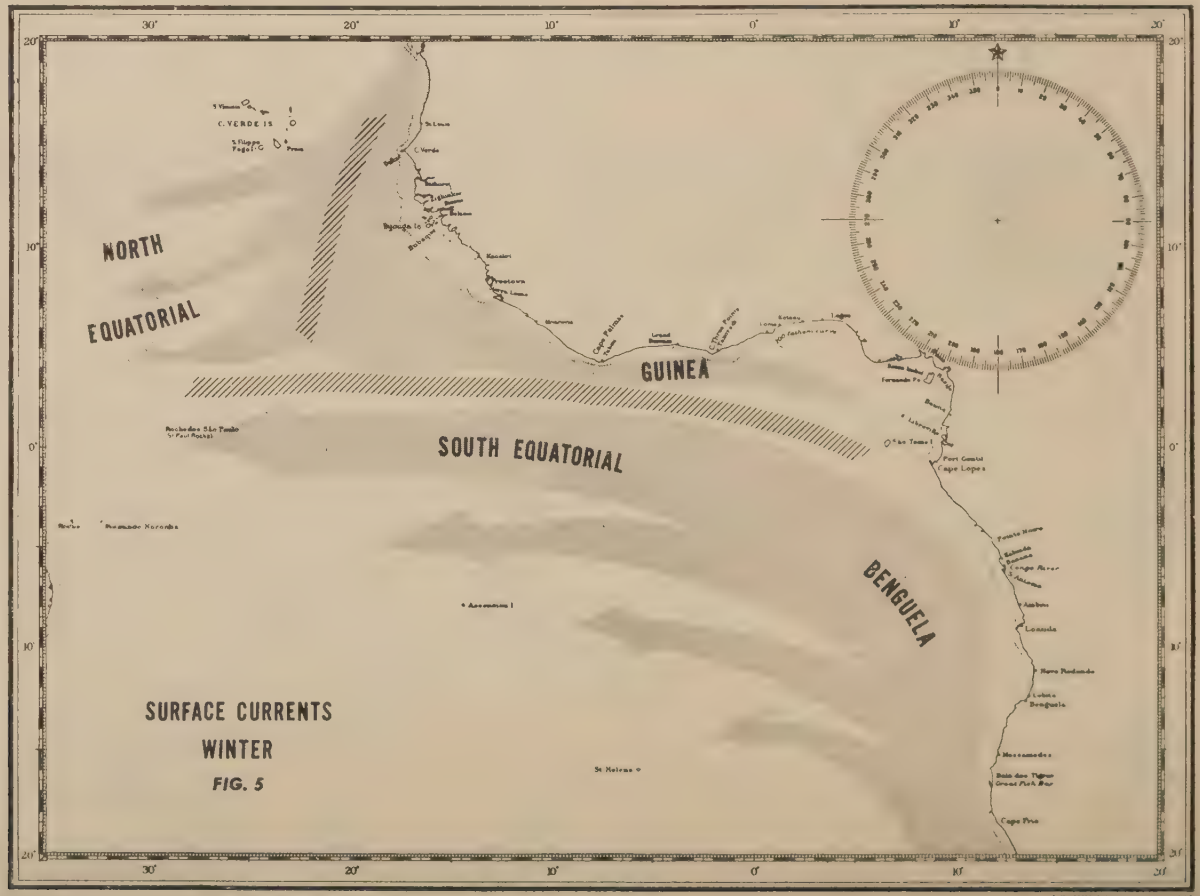
cause the application of these answers could require a difficult reeducation of the African farmers.

A direct solution to this problem would be to utilize the available fishery resources. The implementation of such a plan would require the successful solution of a series of problems, beginning with the production of fish and continuing through processing, distribution, and sale.

For both political and humanitarian reasons we are interested in a solution to the problem of protein dietary deficiencies in Africa, as well as other parts of the world. The stability of the new nations of Africa may depend upon it, and the ability of their peoples to effectively progress will be determined by it.

The fishery resources of West Africa are of a number of kinds. Some of these appear to be of susbtantial magnitude but of a character to be of modest unit worth; these resources are obviously of greatest value


NORTH EQUATORIAL
EQUATORIAL COUNTERCURRENT
GUINEA
SOUTH EQUATORIAL
BENGUELA
C. VERDE IS
Dakar
Monrovia
Cape Palmas
Grand Bassam
Lagos
Fernando Po
Libreville
Port Gentil
Cape Lopez
Fernando Noronha
Ascension I
St Helena
Pointe Noire
Congo River
Ambriz
Loanda
Novo Redondo
Lobito Benguela
Mossamedes
Bom dos Tigres
Great Fish Bay
Cape Frio
SURFACE CURRENTS
SUMMER
FIG. 4


NORTH
EQUATORIAL
GUINEA
SOUTH EQUATORIAL
BENGUELA
C. VERDE IS
St Helena
Ascension I
Fernando Noronha
Rocheder São Paulo
or Paul Rocks
Fernando Po
São Thomé I
Port Gentil
Cape Lopez
Loanda
Lobito
Benguela
Mossamedes
Cape Frio
SURFACE CURRENTS
WINTER
FIG. 5

24°
24°
26°
27°
27°
28°
26°
24°
20°
SURFACE TEMPERATURES
FEBRUARY
FIG. 6

26°
26°
27°
28°
27°
26°
24°
22°
20°
18°
19°
C. VERDE IS.
SURFACE TEMPERATURES
AUGUST
FIG. 7

as a source of protein in the local diet. Food products based on their use should be most reasonable in cost, other factors being equal. The tropical sardines certainly and possibly some of the demersal fishes are of this kind. Others such as the tunas, being predatory fishes feeding on fish such as the sardines, are likely to be less abundant. In view of the world demand for tunas, the possibility of basing a low cost product for local consumption on their use is poor; however, their exploitation in the waters of the eastern tropical Atlantic would, by reason of the establishment of fishing bases, freezers and canneries, provide considerable income to the people of West Africa.

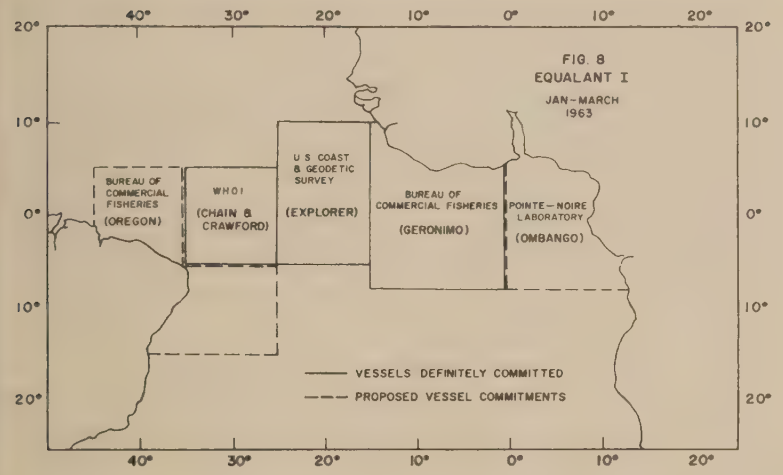
Two research programs, in which we have considerable interest, are now being developed in the fisheries and oceanography of the eastern tropical Atlantic and the waters of the Gulf of Guinea. In addition, there are a number of programs involving both fisheries and oceanographic research now in being which are the individual responsibility of some of the nations of West Africa. These national programs are less in scope than the two mentioned above.

One of these is a survey of the demersal fishes of the African continental shelf. This program is to be conducted by C.C.T.A. which is a regional scientific and technical organization of certain of the African nations south of the Sahara. This organization has applied to the United States for funds to conduct the program and AID (Agency for International Development) has definitely agreed to support it.

The plans involve the use of two trawlers of about 200 to 250 tons to define the limits of trawlable areas between Cape Blanc (Mauritania) and Angola and to determine the nature and abundance of the trawlable fishes. Some oceanographic and bottom data will be taken at each trawling station to relate to the catch. The work will be done in 1963 in two periods of four months duration, the first from January 1 to April 30, and the second from July 1 to October 30. This will permit the survey to cover the two principal climate and fishing seasons in these waters, and the entire area will thus be covered twice.

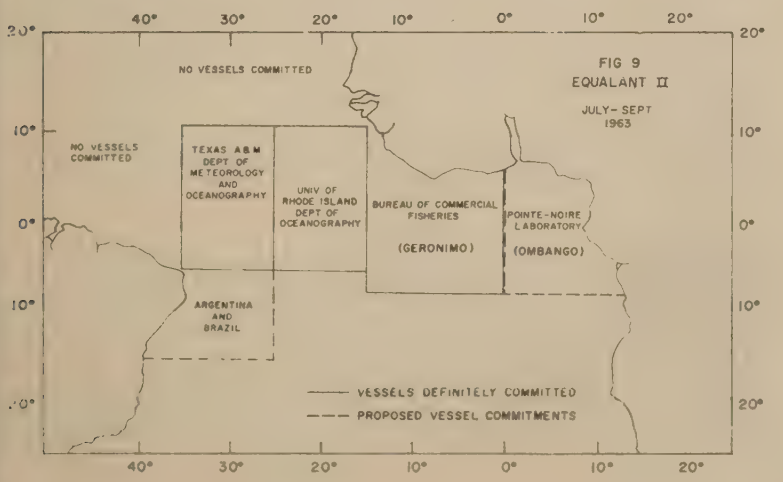
Research vessels of some of the African nations, such as those at Abidjan on the Ivory Coast, Lagos in Nigeria, and Pointe-Noire in French Congo will investigate selected areas during the period of seasonal change—that is during May and June.

The Bureau of Commercial Fisheries is planning a major fisheries and oceanographic research effort in the eastern tropical Atlantic beginning about this same time and coordinated with the program of C.C.T.A. The Bureau's will be concerned with the pelagic fishery resources and the oceanography of the Gulf of Guinea and the eastern tropical Atlantic from about Latitude 20°N to Lat. 15°S and from the African coast to Longitude 30°W. This program was proposed to the



Interagency Committee on oceanography (ICO), and was approved by that group. Currently, the program is under active consideration by ICO for submission to the Intergovernmental Oceanographic Commission as a U. S. sponsored International program.

A suitable vessel will be converted for the program to be ready by January 1963, which will be followed by a second vessel conversion to be ready a year later.



As part of our planning for this program, we have begun a review of what is known concerning the oceanography of the eastern tropical Atlantic.

As may be seen from Fig. 4, the surface currents are complex. During the northern hemisphere summer, the Equatorial Countercurrent is strongly developed, and is the source water for the Guinea current. During the northern hemisphere winter (Fig. 5), on the other hand, the Equatorial Countercurrent is missing, and the North Equatorial Current system is the source water for the Guinea current. The Equatorial Countercurrent water is warm, very saline, and nutrient poor, while the North Equatorial is cooler, more nutrient rich water. Thus we may expect dramatic changes in the distribution of the biota, as well as the weather, in the Gulf of Guinea area. The role of the Equatorial Undercurrent in this area is not clearly understood.

In Fig. 6, showing surface temperatures for February, warm water extends all across the equatorial area, with a pocket of the warmest water in the Gulf of Guinea. During August (Fig. 7), the whole area is affected by cold upwelled water from the south, and by cold water from the north. It is already evident from our review that general knowledge of changes in the biota associated with the physical environmental factors of the area is lacking.

We have, therefore, planned the first year's work (1963) to be oceanography of a general descriptive nature. As a consequence, we invited persons doing oceanographic research, and with a known interest in this area, to a meeting on February 26, 1962, in Washington, D. C., to discuss cooperative research in the tropical Atlantic. Interest was shown by all participants, and plans for synoptic oceanographic surveys of the entire equatorial Atlantic circulation during two periods of calendar 1963 are being developed, called *Equalant I* and *Equalant II*.

It is planned that pelagic fisheries survey work will be carried out during calendar 1964, and 1965, using results from the 1963 work for experimental design of later work.

DISCUSSION

Discussion Leader Manville: Thank you very much, Mr. Wilson. We have been taken further afield and in a different direction than heretofore this morning. This whole program is a fascinating one, and one quite new to me. Any of you from South Africa or Japan, or for that matter closer to home, are invited to pose your questions to the speaker.

Mr. Clark: I was very interested in seeing what was presented here by Dr. Wilson in terms of big-scale cooperative oceanographic work because we are involved also in the sponsorship of large-scale oceanographic survey programs to extend all along the Atlantic Coast and perhaps into the Gulf of Mexico. The period during which this work will get under way coincides rather well with some of the work proposed in this paper, and I know that there are other large-scale

oceanographic survey programs being launched or proposed. So it appears to me that by 1964 or 1965 there will be a very extensive network of oceanographic survey work being carried out in the Atlantic. Fortunately a lot of it will be directed toward the environment of the sea rather than environment of animals, which is very encouraging to all of us people who are interested in the ecology of the sea and not just the physical properties of the ocean.

CHAIRMAN CROKER: I would like to express, on behalf of all the sponsoring organizations, our thanks for the speaker participation in this really far-flung and widespread program this morning. I am only sorry that our other speaker, Dr. Chapman, was called overseas and could not give his paper, which would, in a sense, tie in the topics that the other speakers touched upon. It is a really big development in the interim to provide food for a hungry world. The oceanographic programs are going forward in all the seas of the world and a tremendous awakening in resources and latent research certainly points for an exciting future in the salt and fresh water world.

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Differentiation of Stocks

INTRODUCTION

DIFFERENT POPULATIONS of the same species of fish usually exhibit differences in one or more characteristics such as meristic counts, blood types, scale structure, body proportions, and degree of parasitic infestation. Sometimes these differences are sufficiently large and stable to differentiate the populations to a considerable extent, if not completely. In such cases, they can be used to develop procedures for classifying fish to the different populations and to estimate the relative abundance of different populations in areas of intermingling.

In this paper we will review some statistical procedures for classifying fish in a mixed population on the basis of differences in characteristics, and for estimating the relative abundance of different populations in areas of intermingling.

In practice, certain important details must be considered. These include sampling, the selection of characters, intra-population variations, definition of populations, measuring errors of classification, specifying alternatives for classifying mixed populations, and examining the consequences of incorrect specification of alternatives. However, in this paper we will confine our attention to only the basic procedures for classification.

We will present a few examples involving only two populations in an area of intermingling, and one example involving more than two populations. For one of the examples involving two populations, we will also describe a procedure for estimating the variance of the estimate of relative abundance.

TWO POPULATIONS PRESENT IN THE MIXING AREA

ONE CHARACTER AVAILABLE

Let us first consider the case where a particular character occurs in only one of two fish populations. The character may be a parasite, a distinctive marking on the scales, or perhaps an artificial mark such as a clipped fin. This character may or may not be possessed by all individuals in the population of fish in which it occurs.

Suppose that the two populations, A and B, intermingle in a certain area. Our problem is to estimate the relative abundance of A and B in that area. We can proceed by taking a sample of n fish from the mixed population and determining the number of them which have the character in question.

Assuming that the character occurs in population A, the number of fish (r) in the sample having the character is identically equal to:

$$r = p_a f_a n \tag{1}$$

where p_a is the frequency of occurrence of the character among the fish from population A in the mixed sample and f_a is the proportion of the mixed sample composed of fish from population A.

Assuming that n, p_a, and r are known, we could compute f_a from,

$$f_a = \frac{r/n}{p_a} \tag{2}$$

Perhaps a more likely situation is that some of the fish from population B also possess the character in question. The two populations then differ only in the frequency of occurrence of the characteristic. Thus, the fish in the mixed sample having the characteristic may be from either of the two populations. In this case r is identically equivalent to:

$$r = p_a f_a n + p_b f_b n$$

where p_a and f_a are as defined before and p_b and f_b are the corresponding quantities for population B.

Noting that $f_b = 1 - f_a$, f_a is then given by:

$$f_a = \frac{(r/n) - p_b}{p_a - p_b} \tag{3}$$

Since the quantities p_a and p_b are unknown one must estimate them by sampling populations A and B separately. Let us call these estimates P_a and P_b. An estimate of f_a is then:

$$\hat{f}_a = \hat{F}_a = \frac{(r_a/n) - P_b}{P_a - P_b} \tag{4}$$

This is also an estimate of F_a, the relative abundance of fish from population A in the area from which the mixed sample was drawn.

Thus far we have assumed that populations A and B are dichotomous with respect to the available character. Suppose now that the character is possessed by all fish in the two populations but that it takes on a range of values. Such a character might be the number gill rakers or the length of some body part. The character may be either discrete or continuous. For convenience we will assume that the character is discrete. The following, however, applies equally to a continuous character if the values of the character are first assigned to class intervals.

We proceed as in the dichotomous case, but now use the differences between populations in the frequency distributions of the character.

Suppose that R_1 is the proportion of a mixed sample falling into the first category of the frequency distribution. This of course is an observed quantity. Writing the expected value of R_1 and equating it to the observed value we have:

$$P_{a1} F_a + P_{b1} F_b = R_1$$

If there are n categories in the frequency distribution we have n such relations:

$$\begin{aligned} P_{a1}\,F_a + P_{b1}\,F_b &= R_1 \\ P_{a2}\,F_a + P_{b2}\,F_b &= R_2 \\ \cdot \qquad\quad \cdot &\qquad \cdot \\ \cdot \qquad\quad \cdot &\qquad \cdot \\ \cdot \qquad\quad \cdot &\qquad \cdot \\ P_{an}\,F_a + P_{bn}\,F_b &= R_n \end{aligned} \tag{5}$$

where P_{ai} = relative frequency of the character in the ith category for population A
P_{bi} = same for population B
F_a = relative abundance of fish from A in the mixing area sampled.
$F_b = 1 - F_a$
R_i = relative frequency of the character in the ith category for the mixed sample.

An estimate of the relative abundance of fish from population A and B can then be obtained as the least squares solution of these n equations (assuming that P_{ai} and P_{bi} are known).

The problem of estimating F_a and F_b is greatly simplified if the range of the character is collapsed into just two categories. Let us call the categories a and b. The estimating equations are then:

$$\begin{aligned} P_{aa}F_a + P_{ba}F_b &= R_a \\ P_{ab}F_a + P_{bb}F_b &= R_b \end{aligned} \tag{6}$$

Thus an estimate of F_a is given by:

$$\hat{F}_a = \frac{R_a - P_{ba}}{P_{aa} - P_{ba}} \tag{7}$$

where P_{aa} and P_{ba} are estimated by sampling population A and B separately.

TWO OR MORE CHARACTERS AVAILABLE

In this case the problem of estimating the relative abundance of the two populations in an area of mixing can be approached as in the preceding example. The only difference is that P_{ai} is replaced by $P_a(x_1, \ldots x_n)_i$, P_{bi} by $P_b(x_1, \ldots x_n)_i$ and R_i by $R(x_1, \ldots x_n)_i$. The subscript $(x_1, \ldots x_n)_i$ refers to the relative frequency of the n characters, $(x_1, \ldots, x_n)$, taken together in the ith subsclass.

Theoretically, then, the above procedure is applicable for any number of characters. It is easily seen, however, that the number of subclasses and thus the number of equations increases quite rapidly with the addition of each character. Even for two characters the number of equations involved in estimating F_a and F_b may be quite large. Therefore it is desirable to reduce the number of estimating equations. Since there are only two populations involved, two such equations are sufficient.

There are a great number of ways that the subclasses can be combined in order to reduce the number of estimating equations. What is needed, however, is an objective procedure which retains the maximum possible difference between the two populations.

A technique which is very useful for this purpose is the discriminant function. Briefly, the discriminant function is a linear combination of the characters which best separates the two populations involved. It is best in the sense of providing the maximum difference in means of the linear combination between the two populations relative to the variation within populations. The procedures for computing a discriminant function can be found in a text by Rao (1952).

We can write the discriminant function, Y, as:

$$Y = m_1x_1 + m_2x_2 + \cdots\cdots + m_nx_n \tag{8}$$

where x_i represents the ith character and the m's represent constants which are determined from the variances, covariances and means of the characters for the two populations.

We next determine the frequency distribution of Y and the mean values of Y for the two populations A and B. Let us denote these means by $\overline{Y}_a$ and $\overline{Y}_b$. We proceed to collapse the frequency of Y in the two populations by selecting a particular Y value, Y_o, defined by:

$$Y_o = \frac{\overline{Y}_a + \overline{Y}_b}{2}$$

One category then consists of all Y values falling on the same side of Y_o as does Y_a; the other, of all Y values falling on the other side of Y_o (i.e., those falling on the same side of Y_o as does Y_b). In the usual applications of the discriminant function these two categories are referred to as those individuals classified to population A and B respectively. For our purposes, however, we shall simply call them category a and category b.

Here again, it must be remembered that for a mixed sample the fish falling into category a may be composed of both population A fish and population B fish. Thus our estimating equations and the resulting estimate of F_a are exactly as presented above. That is, F_a is estimated by:

$$\hat{F}_a = \frac{R_a - P_{ba}}{P_{aa} - P_{ba}} \qquad (9)$$

It should be pointed out again that P_{aa} and P_{ba} must be estimated from samples of fish taken from population A and B separately.

MORE THAN TWO POPULATIONS PRESENT, n CHARACTERS AVAILABLE

The methods presented in the preceding section can be extended to the problem of determining the relative abudance of more than two populations in an area of mixing. In the preceding section two categories were constructed into which individual fish were classified. Here, we shall proceed along similar lines by constructing as many categories as there are parent populations.

This can be done by computing a discriminant function for each pair of populations. The categories for each population, as well as for a mixed sample, then become: (1) those fish classified to population A, (2) those fish classified to population B, (3) those fish classified to population C, and so on. We shall denote these categories by a, b, c, d, etc.

To illustrate the procedure let us consider the following example. Assume that there are four populations present in the area of mixing, and that the six possible discriminant functions have been computed, and that the procedure for collapsing the frequency of each into two categories has been determined. This can be represented diagramatically by:

Function	Classification rule
Y_{ab}	category a $<$ Y_{oab} $<$ category b
Y_{ac}	category a $<$ Y_{oac} $<$ category c
Y_{ad}	category a $<$ Y_{oad} $<$ category d
Y_{bc}	category b $<$ Y_{obc} $<$ category c
Y_{bd}	category b $<$ Y_{obd} $<$ category d
Y_{cd}	category c $<$ Y_{ocd} $<$ category d

The left column represents the discriminant function for the pair of populations indicated by the subscripts. The column on the right represents the six classification rules.

For example, an individual is assigned to category a rather than b if its Y_{ab} value is less than Y_{oab}. Each of the values Y_{oij} is determined in exactly the same way as in the preceding section.

As indicated by the six classification rules, we have assumed that: (1) the means for population A, $\overline{Y}_a(_{ab})$, $\overline{Y}_a(_{ac})$, and $\overline{Y}_a(_{ad})$, are numerically less than the corresponding values Y_{oab}, Y_{oac}, and Y_{oad}; (2) the means for population B, $\overline{Y}_b(_{bc})$ and $\overline{Y}_b(_{bd})$ are numerically less than the corresponding values Y_{obc} and Y_{obd}; and (3) the mean of population C, $\overline{Y}_c(_{cd})$, is numerically less than the value $Y_{o(cd)}$.

We are now in a position to classify an individual fish to its proper category. Suppose the Y values for the ith fish are as follows:

$$\begin{aligned} Y_i(_{ab}) &> Y_{oab} \\ Y_i(_{ac}) &> Y_{oac} \\ Y_i(_{ad}) &> Y_{oad} \\ Y_i(_{bc}) &> Y_{obc} \\ Y_i(_{bd}) &> Y_{obd} \\ Y_i(_{cd}) &> Y_{ocd} \end{aligned}$$

According to the first function, Y_{ab}, the fish is classified or placed in category b. This means that category a is *excluded* from further consideration. We next go to the function Y_{oc}. Here the fish is placed in category c. Hence, both categories a and b are excluded. For the remaining function, Y_{cd}, category d is excluded. Thus the fish is placed in category c.

In this way all fish in a mixed sample and in the samples taken from the four populations separately are classified into one of the four categories. It should be noted that the category selected (category c) for the fish in the above example is unique. That is, the same result is obtained regardless of the order in which the functions are considered. In our example, we are assured of a unique placement for each fish because the six rules define four mutually exclusive regions in three dimensional space—each region corresponding to one of the four categories. The populations can be represented in three dimensional space because only three of the six discriminant functions are functionally independent. That is, if we assume that the first three functions, Y_{ab}, Y_{ac} and Y_{ad}, are given, then the last three, Y_{bc}, Y_{bd}, and Y_{cd}, can be derived by simply taking the difference between corresponding coefficients of particular pairs of the first three functions. For example, the coefficients of the function Y_{bc} are given by subtracting the coefficients of the function Y_{ab} from the corresponding coefficient of the function Y_{ac}. If we denote such a subtraction by $(Y_{ac} - Y_{ab})$, then Y_{bd} is given by $(Y_{ad} - Y_{ab})$ and Y_{cd} is given by $(Y_{ad} - Y_{ac})$.

For the case of P populations there will be $(1\text{-}P)P/2$ rules defining P mutually exclusive regions in (P-1) dimensional space—each region corresponding to one of the P categories we wish to construct. Thus there is always a unique placement of each fish into one of the P categories.

To estimate the relative abundance of a population in a mixing area when there are more than two populations present it becomes necessary to solve a set of simultaneous equations. These equations arise from considerations similar to those in the preceding section. Let us continue with our example of four populations.

In a mixed sample we would expect the following proportions to be classified to the four categories a, b, c and d:

$$\begin{aligned} P_{aa}F_a + P_{ba}F_b + P_{ca}F_c + P_{da}F_d &= \hat{\bar{R}}_a \\ P_{ab}F_a + P_{bb}F_b + P_{cb}F_c + P_{db}F_d &= \hat{\bar{R}}_b \\ P_{ac}F_a + P_{bc}F_b + P_{cc}F_c + P_{dc}F_d &= \hat{\bar{R}}_c \\ P_{ad}F_a + P_{bd}F_b + P_{cd}F_c + P_{dd}F_d &= \hat{\bar{R}}_d \end{aligned} \qquad (10)$$

In equation 10 P_{ij} is the proportion of fish in the ith population expected to be placed in the jth category. These proportions are estimated by sampling the four populations separately. F_i is the relative abundance (expressed as a proportion) of the ith population in the area of mixing, and $\hat{R}_j$ is the expected proportion of the mixed sample placed in the jth category.

For any mixed sample we can estimate F_a, F_b, F_c, and F_d by equating the expected values $\hat{R}_a$, $\hat{R}_b$, $\hat{R}_c$, and $\hat{R}_d$ with their actual values. By noting that $F_d = 1 - F_a - F_b - F_c$; these estimates are given as the least squares solution of the set of equations:

$$\begin{aligned}
(P_{aa} - P_{da})\ \hat{F}_a + (P_{ba} - P_{da})\ \hat{F}_b + (P_{ca} - P_{da})\ \hat{F}_c &= R_a - P_{da} \\
(P_{ab} - P_{db})\ \hat{F}_a + (P_{bb} - P_{db})\ \hat{F}_b + (P_{cb} - P_{db})\ \hat{F}_c &= R_b - P_{db} \qquad (11) \\
(P_{ac} - P_{dc})\ \hat{F}_a + (P_{bc} - P_{dc})\ \hat{F}_b + (P_{cc} - P_{dc})\ \hat{F}_c &= R_c - P_{dc}
\end{aligned}$$

Here, R_a, R_b, and R_c are the actual proportions of the mixed sample, classified to categories a, b, and c.

In some applications the number of populations may be quite large and the differences between certain pairs of the populations relatively small as compared with the differences between other pairs. In such cases it is best to first combine the populations into larger units.

This combination of the populations can be accomplished by applying a technique known as the distance function (Rao, 1952). The distance function measures the relative difference between two populations. Mathematically it is defined as:

$$D^2 = \sum_{i=1}^{P} \sum_{j=1}^{P} w^{ij}\ (\overline{X}_{ia} - \overline{X}_{ib})\ (\overline{X}_{ja} - \overline{X}_{jb}), \qquad (12)$$

where p is the number of characters, w^{ij} is the inverse of the variance-covariance matrix pooled over all populations), $\overline{X}_{ia}$ is the mean of the ith character for population A and $\overline{X}_{ib}$ is the mean of the ith character for population B.

More specifically, D^2 measures the overlap in frequency distribution between two populations. The frequency distribution it refers to is the frequency of a linear combination of the characters—the same linear combination that arises from a discriminant function analysis. Thus the larger the D^2 is between two populations the smaller the overlap.

Having computed the D^2 values between all pairs of populations, one can then cluster the populations into units or groups of populations. The procedure involved can be found in the text by Rao (1952).

Discriminant functions can next be computed for each pair of population groups. Relative abundance estimates will of course apply to the groups and not necessarily to any particular population.

VARIANCE OF THE ESTIMATE OF RELATIVE ABUNDANCE

Having presented some procedures for estimating the relative abundance of fish from one population in an area of mixing, we now consider the problem of estimating the variance of this estimate and of determining the associated confidence interval. This will be done for the case of two populations present in the area of mixing.

The estimate of the relative abundance of one of the populations (say, population A) in the area of mixing is:

$$\hat{F}_a = \frac{R_a - P_{ba}}{P_{aa} - P_{ba}} \qquad (13)$$

We shall derive the variance of $\hat{F}_a$ under the assumption that P_{ba} and P_{aa} are known (or estimated with negligible error). Thus, variation in $\hat{F}_a$ is entirely due to the variation in R_a. This variation arises from two sources: (1) sampling errors involved in obtaining the true proportion of fish from population A in the area of mixing, and (2) variation in the proportions of fish assigned to the two categories a and b for each of the two populations.

The variance of $\hat{F}_a$ can be written as:

$$V(\hat{F}_a) = \left(\frac{1}{(P_{aa} - P_{ba})}\right)^2 V(R_a) \qquad (14)$$

The derivation of the variance of R_a is shown in Appendix A. Under certain assumptions regarding the distributions and expected values of the quantities involved, the variance of $\hat{F}_a$ is approximately given by:

$$V(\hat{F}_a) = \left(\frac{1}{P_{aa} - P_{ba}}\right)^2 \left(\frac{1}{n}\right) [\hat{F}_a \hat{F}_b (P_{aa} - P_{ba})^2 + \hat{F}_a (P_{aa} P_{ab} - P_{ba} P_{bb}) + P_{ba} P_{bb}]$$

An interval estimate for F_a is then:

$$\hat{F}_a - k\sqrt{V(\hat{F}_a)} \qquad \text{to} \qquad \hat{F}_a - k\sqrt{V(\hat{F}_a)}$$

Assuming F_a to be normally distributed we would expect such an interval to include F_a approximately 95 percent of the time when $k = 1.96$, approximately 90 percent of the time when $k = 1.64$ and so on.

We conducted a sampling experiment to check the accuracy of this variance estimate and the resulting confidence interval. A hypothetical mixed population of 1000 fish — 700 from population A and 300 from population B — was constructed. The proportions of fish from A and B which would be assigned to category a were set at 0.75 (P_{aa}) and 0.20 (P_{ba}) respectively.

From this mixed population of 1000 fish, we drew 398 samples (each of size 100) with replacement. Using the actual values of P_{aa} and P_{ba} in the formulas presented above, we then computed $\hat{F}_a$, $V(\hat{F}_a)$, and the resulting 95 percent confidence interval estimate for F_a for each of the 398 samples.

In comparing the expected quantities with the observed quantities we obtained the following: (1) the average value of $\hat{F}_a$ (from the 398 observations) was 0.703, which is quite close to the value of 0.70; (2) the variance of $\hat{F}_a$ (from the 398 observations) was 0.00827, which is in good agreement with the variance of 0.00803 given by the derived estimate; and (3) 94.2 percent of the 398 confidence intervals included the true value of F_a, which agrees well with the expected 95 percent.

The above hypothetical case is not all-inclusive; still, the results obtained appear to justify accepting the proposed approximation of the variance $\hat{F}_a$.

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APPENDIX A

DERIVATION OF THE VARIANCE OF F_a

Let us define the problem as follows: There exist two populations of fish, A and B,

which differ with respect to some measurable characteristic(s). Furthermore, a rule is available for classifying individual fish into two categories, a and b. A sample is then taken from a population composed of fish from both A and B. According to the classification rule a certain proportion of the fish in this sample are assigned to category a. On the basis of this classification, and assuming we know the expected proportions of A and B falling into category a, we then wish to estimate the relative abundance of A in the mixed population and the variance of this estimate.

Recall that an estimate of F_a is given by:

$$\hat{F}_a = \hat{f}_a = \frac{R_a - P_{ba}}{P_{aa} - P_{ba}} ,$$

where P_{aa} and P_{ba} are the expected proportions of A and B falling in category a, and R_a is the observed proportion of the mixed sample assigned to category a.

By assumption P_{aa} and P_{ba} are known quantities. Therefore, the variance of $\hat{F}_a$ is:

$$V(\hat{F}_a) = \left(\frac{1}{P_{aa} - P_{ba}}\right)^2 V(R_a) .$$

Recall also that R_a is identically equal to:

$$R_a = p_{aa} f_a + p_{ba} f_b$$

where p_{aa} and p_{ba} are the actual, but unknown, proportions of the fish in the mixed sample from A and B assigned to category a, and f_a and f_b are the actual, but unknown, proportions of A and B in the mixed sample.

The variance of R_a can be written as:

$$V(R_a) = V(p_{aa}f_a) + V(p_{ba}f_b) + 2\ \mathrm{cov}[(p_{aa}f_a)\ (p_{ba}f_b)] \qquad (1)$$

At this point it is important to note the following:

(a) the expected values of p_{aa} and p_{ba} are P_{aa} and P_{ba}
(b) the expected values of f_a and f_b are F_a and F_b.
(c) the quantites p_{aa}, p_{ba}, and f_a are mutually independent.
(d) the quantities f_a and f_b are functionally dependent,
i.e., $f_b = 1 - f_a$.

Thus the variance of $(p_{aa}f_a)$ can be approximated by:

$$V(p_{aa}f_a) = p_{aa}^2\ V(f_a) + f_a^2\ V(p_{aa}) \qquad (2)$$

Similarly,

$$V(p_{ba}f_b) = p_{ba}^2\ V(f_b) + f_b^2\ V(p_{ba}) \qquad (3)$$

The covariance term in (1) can be written as (substituting $(1-f_a)$ for f_b):

$$\mathrm{cov}\ [(p_{aa}f_a)\ (p_{ba}f_b)] = E[p_{aa}f_a p_{ba}\ (1\text{-}f_a)] - E\ (p_{aa}f_a)\ E[p_{ba}\ (1\text{-}f_a)]$$

where E ( ) denotes the expectation of the indicated quantity.

Expanding the right hand side gives:

$$\mathrm{cov}\ [(p_{aa}f_a)\ (p_{ba}f_b)] = E(p_{aa}p_{ba}f_a) - E(p_{aa}p_{ba}f_a^2) - E(p_{aa}f_a)\ [E(p_{ba}) - E(p_{ba}f_a)]$$

Since p_{aa}, p_{ba} and f_a are mutually independent, then:

$$\mathrm{cov}\ [(p_{aa}f_a)\ (p_{ba}f_b)] = -E\ (p_{aa})\ E\ (p_{ba})\ [E(f_a^2) - (E\ (f_a)^2]$$
$$= -P_{aa}\ P_{ba}\ V(f_a) \qquad (4)$$

Subsituting (2), (3), and (4) in (1), we write the variance of R_a as:

$$V(R_a) = p_{aa}^2\ V(f_a) + f_a^2\ V(p_{aa}) + p_{ba}^2\ V(f_b) + f_b^2\ V(p_{ba}) - 2\ P_{aa}\ P_{ba}\ V(f_a)$$

Assuming that p_{aa}, p_{ba}, and f_a follow the binomial distribution, the variance of $\hat{F}_a$ (noting that $V(f_a) = V(f_b)$ becomes:

$$V(\hat{F}_a) = \left(\frac{1}{(P_{aa} - P_{ba})}\right)^2 \left[\frac{F_a\,(1 - F_a)}{n}\,(P_{aa}^2 - 2\,P_{aa}P_{ba} + P_{ba}^2) + f_a^2\left(\frac{P_{aa}\,P_{ab}}{f_a n}\right) + f_b^2\left(\frac{P_{ba}\,P_{bb}}{f_b n}\right)\right]$$

where $P_{ab} = 1 - P_{aa}$, $P_{bb} = \quad - P_{ba}$, and n is the size of the mixed sample.

Since F_a, p_{aa}, and p_{ba} are unknown, the variance of F_a must be approximated by substituting the estimated and expected values for these quantities. That is, we will substitute $\hat{F}_a$ for F_a, P_{aa} for p_{aa}, and P_{ba} for p_{ba}. The approximate variance is then given by:

$$V(\hat{F}_a) = \left(\frac{1}{P_{aa} - P_{ba}}\right)^2 \left(\frac{1}{n}\right) [\hat{F}_a\hat{F}_b\,(P_{aa} - P_{ba})^2 + \hat{F}_a\,(P_{aa}P_{ab} - P_{ba}\,P_{bb}) + P_{ba}P_{bb}]$$

DISCUSSION

DR. LINDSEY: All the methods that you have described depend upon having what you call pure populations as a standard of comparison, and you suggest that the best place to get these is close to the spawning ground. But particularly in pink salmon, spawning runs will contain a certain proportion of strays, and it seems to me that the presence of a few strays might be very important in widening the range of the discriminate score in one population. Is it possible for you to start with a mixed population, such as you might get on a spawning bed, and compare it with another population, whether the other population is pure or is made up a mixture of two separate races?

MR. FREDIN: This matter of straying probably would increase the range of the discriminant value of a standard population of pink salmon where you have, say, numerous spawning streams and separate races in any particular area. You might be better off, after tagging, to sample a mixed population which is caught by the fishermen in a particular area. This way you might get a better measure or indication of the racial composition of racial characteristics of a stock of mixed races than by sampling in just one stream or two streams.

DR. LINDSEY: But if you don't have any information on tagging, have you a mathematical technique for looking for the possibility of two origins in one sample?

MR. FREDIN: I suspect that the best thing to do in a case like that would be to take the sample and look at the distribution of the characteristics that you are interested in, and check for such things, say, as bimodalty.

DR. WILIMOVSKY: Wouldn't the distribution of the clusters in a D square analyses answer Dr. Lindsey's question, assuming you didn't get into a topological problem?

MR. FREDIN: I think perhaps it would, yes.

DR. SHEPARD: I found your paper very interesting, Mr. Fredin, and I think it has wide applicability to problems of separating races of fish.

There is one difficulty, though, that I can't see this sort of approach overcoming, and I have not been able to find any other approach, either. I would appreciate your comments on the problem where for a number of species of salmon, the characteristics, rather than forming into groups of populations that have similar characteristics here and there, have a gradual climb from one end of the distribution range to the other. Thus, you are dealing with more or less a continuous change in the nature of the characteristics. I don't quite see how the generalized distance function can provide you with groupings of different categories. Rather, your problem is in trying to fit the likely origin of the fish within a spectrum of possibilities that change very gradually from one place to another. I was just wondering if there is any different approach to this sort of problem than the one you have described.

MR. FREDIN: This would be a problem, as you say, in setting up, say, a cut-off point, whether you cut off here or whether you cut off there.

I think that what happens in a case like this is that one would set up some cutting-off point for classifying fish into this or that area. You might have a fairly sizeable error of classication. This may or may not be a difficult problem to

correct. I haven't looked at the problem from the standpoint of errors of classication of fish in a situation like this, so I can't answer your question very well.

DR. ROYCE: It seems to me that it is important to separate the uses of discriminate functions and generalized distance functions as a means of classifying individuals. The distance function is a means, really, of comparing the groups. I got the impression that you said that you would use the generalized distance function to classify things into groups.

MR. FREDIN: To set up clusters or constellations.

DR. ROYCE: This is a rather unsatisfactory classification, it seems to me. It really doesn't work very well.

The generalized distance function, to my way of thinking, really represents a way of determining the maximum amount of genetic interchange that may be occurring.

MR. FREDIN: We have used the generalized distance function to set up these clusters or constellations. In some cases, in red salmon, in particular, we have been quite pleased with the types of clustering we have arrived at using the generalized distance function.

DR. LARKIN: May I ask a question and make an observation at the same time? Dr. DiCostonzo recently applied one of these sets of equations, like you have, for estimating what proportions of the catch in Bristol Bay came from the various streams tributary. Knowing the age distribution of the spawning population in the various streams and the age distribution in the catch, you can use this set of equations in having a go at estimating what proportions of the catch comprises fish from the different systems.

In the first round of estimates, some of the streams came up with negative populations. minus 165,000 fish, which underlined that the character in question, age, was influenced in the catch not only by the numbers of fish of particular age, but also by their availability to the commercial fishery.

Is there any possibility that the kinds of characters that you are using are influenced in their occurence by the availability of fish that have these kinds of characters to the fishery?

MR. FREDIN: Yes, of course, there is a possibility that selectivity for length or age would give you an unrepresentative sample from a population.

To correct for this, in our studies, we have, first of all, checked for correlation of length with the other characters and, in most cases, we have found the correlation to be extremely low. Nevertheless, we have included length as one of our characters for determining the coefficient, these "L's" we have talked about here. We include length as character number one. In subsequent analyses, we strike that out, in effect then, reducing the problem to one of working with fish of the same size.

DR. KASAHARA: I think you haven't mentioned one of the basic points in relation to all these problems you have described, and that is you must know what alternatives are in the given sample. You must know all the populations which might be included in the sample of fish. If you don't know how many or what populations are contributing to the fish of certain samples, you can't do this analysis.

Taking an example: There are ten herring populations distributed around the coast. You have a mixed sample in a certain area. You must know, among these ten populations, what populations are positively contributing to this mixed sample. From biological data, tagging experiments, or other evidence, you must know the population distribution. You must have a priori information and you must have a pattern, isn't that true?

MR. FREDIN: Yes, it helps. Of course, as you say, we could use a tagging experiment to determine the possible contributions of various stocks in an area of intermingling. The generalized distance function also gives us some indication of the possible numbers of stocks which might be in an area of intermingling.

In any event, we come to the question: What difference does it make? In a practical situation we ask this question and we can examine the matter empirically by determining what the consequences might be when we do not consider all the alternatives. In the end, this may be much more important than the considerations of which you speak.

DR. KASAHARA: For instance: we know that there are ten or more or less separate populations of herring, and it makes a lot of difference whether you take into consideration only "A" and "B" as contributors to the sample, or whether you take all ten into consideration. When you are classifying the fish according to the samples, you are

assuming that all the fish in the sample are either "A" or "B". So no matter how close other populations are to these "A" or "B" in the characteristics in question, you just ignore them. Whether you can do it or not makes a difference in the final analysis. You must know the pattern and the possibility of contributions of the different populations. This is a biological and not a statistical problem.

MR. FREDIN: As I say, I think one approach to this is tagging, and I think the use of the distance function analysis helps.

DR. KASAHARA: Distance function might give you the fact that here is a population, and if you have three other far distant populations which, according to the distant function, are pretty close to "A" or "B", you can't make any reasonable assumption without having the biological evidence.

MR. FREDIN: Of course, in that case then, I would try to cluster these populations with "A" or "B".

DR. KASAHARA: What I am pointing out here is that you can't do this from statistics. You have to have very good a priori biological information.

MR. FREDIN: I must agree with you. I think we must have some apriori information. It is my opinion, however, that this can come from tagging. It can come to some extent but not entirely, from the racial data themselves. Certainly, it behooves us to have independent checks on the assumptions and procedures involved, and I think that we shouldn't overlook the fact that it is useful to look into the consequences of failing to consider alternatives.

One final observation, and this is something I have heard from a number of people who have worked with classificatory procedures, that really the important thing is that the procedure works—that is, provides useful information in a practical situation.

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GEOFISICA INTERNACIONAL

REVISTA DE LA UNIÓN GEOFÍSICA MEXICANA, AUSPICIADA POR EL INSTITUTO DE GEOFÍSICA DE LA UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO

G. I. RODEN

ASPECTOS OCEANOGRAFICOS DEL PACIFICO ECUATORIAL ORIENTAL

OCENOGRAPHICAL ASPECTS OF EASTERN ECUATORIAL PACIFIC

Sobretiro del *Reprint from*

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Director: Julián Adem — Subdirector: Manuel Maldonado-Koerdell

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ASPECTOS OCEANOGRAFICOS DEL PACIFICO ECUATORIAL ORIENTAL *

G. I. RODEN * *

RESUMEN

Un rasgo notable de la circulación a lo largo del ecuador es la ocasional contracorriente superficial al oeste de las Islas Galápagos (Puls, 1895). Se desarrolla cuando el esfuerzo del viento cae por debajo de cierto valor crítico (0.25 dinas/cm^{-2} aproximadamente) y parece representar la manifestación superficial de una corriente profunda ecuatorial que circula hacia el este. Una extensión de esta corriente, más allá de las Islas Galápagos, tal vez pueda originar el fenómeno de "El Niño" frente al Perú. Al este de las Islas Galápagos, las corrientes que circulan a lo largo del ecuador forman frecuentemente ángulos rectos con la dirección del viento predominante. La función de dirección de la corriente de transporte de masa total se computó con datos más detallados que los disponibles previamente, encontrándose que a través del año el transporte va hacia el sur a lo largo de la costa peruana y hacia el este entre las latitudes 4° N y 6° N. Un análisis estadístico de largos registros climáticos en Balboa, Z. C. Panamá, para la variación de frecuencia entre cero y seis ciclos por año no pudo destacar periodicidades no-estacionales significantes. Existe una relación inversa relativamente buena entre temperatura y viento y entre nivel del mar y viento para frecuencias entre 1 y 3.5 ciclos por año.

INTRODUCCION

El Pacífico ecuatorial oriental entre la longitud 100° W y América del Sur es peculiar en muchos aspectos. A pesar de encontrarse en un ambiente predominantemente influenciado por los alisios del SE y las calmas y ser afectado estacionalmente por los alisios del NE del Caribe, se caracteriza por una complicada circulación superficial y por una amplia va-

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OCEANOGRAPHIC ASPECTS OF THE EASTERN EQUATORIAL PACIFIC *

G. I. RODEN * *

ABSTRACT

A noteworthy feature of the flow along the equator is the occasional surface countercurrent to the west of the Galapagos Islands (Puls, 1895). It occurs when the wind stress falls below a certain critical value (0.25 dynes/cm^{-2} approximately) and appears to represent the surface manifestation of the eastward flowing equatorial undercurrent. An extension of this current past the Galapagos Islands may conceivably lead to "El Niño" phenomenon off Peru. East of the Galapagos Islands the currents along the equator flow frequently at right angles to the prevailing wind direction. The total mass transport stream line function is computed from more detailed data than have been previously available. It is found that throughout the year the transport is southward along the Peruvian coast and eastward between latitudes 4° N and 6° N. A statistical analysis of long climatic records at Balboa, C.Z. Panama, for the frequency range between zero and six cycles per year failed to bring out any significant non seasonal periodicities. There is a relatively good and inverse relation between temperature and wind, and sea level and wind for frequencies between 1 and 3.5 cycles per year.

INTRODUCTION

The eastern equatorial Pacific between about longitude 100° W and South America is unique in many respects. Lying as it does in an environment predominantly influenced by the SE trades and the doldrums, and seasonally affected by the NE trades from the Caribbean, it is characterized by a complicated surface circulation, and by a large

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riación estacional de vientos, corrientes y temperaturas (Figs. 1 y 4). Los principales rasgos hidrográficos de la región son conocidos desde hace tiempo (Humboldt, 1814; Duperrey, 1829; Virgin, 1858); algunos de ellos, como las corrientes que circulan estacionalmente hacia el este en el ecuador (Puls, 1895) ya estaban olvidados hasta que casi 70 años después nuevamente se hicieron esfuerzos para comprender mejor esta área tan poco conocida (Schott, 1931; Cromwell, Montgomery y Stroup, 1954; Reid, 1959; Wooster y Cromwell, 1958; Wooster y Gilmartin, MS). El actual conocimiento de las corrientes superficiales, según los autores antes mencionados, puede resumirse como sigue: (a) Existen dos corrientes estables que van permanentemente al oeste, la Corriente Ecuatorial del Norte y la Corriente Ecuatorial del Sur y dos corrientes estables que van permanentemente al norte, la Corriente del Perú y la Corriente de Colombia; (b) Existen tres contracorrientes estables que van estacionalmente al este, la Contracorriente Ecuatorial del Norte, la corriente ecuatorial que va al este y la Contracorriente Ecuatorial del Sur. La primera contracorriente en la región considerada circula durante el verano y el otoño del hemisferio norte, la segunda solamente durante la primavera del hemisferio norte y la tercera sólo se ha reportado una vez en Noviembre. Varios intentos se han hecho para explicar teóricamente las corrientes observadas. Ecuaciones linearizadas para movimiento permanente fueron usadas por Sverdrup (1947), Reid (1948), Shtokman (1948), Yoshida (1959) y Arthur (1960). Ecuaciones no-lineares para movimiento permanente fueron aplicadas por Fofonoff (1954), Charney (1960), Veronis (1960) e Hidaka (1961). Sin embargo, la mayoría de los autores se refirieron a las condiciones al oeste de las Islas Galápagos.

seasonal variation in winds, currents and temperatures (Figs 1 and 4). The main hydrographic features of the regio were recognized long ago (Humboldt, 1814; Duperrey 1829; Virgin, 1858); some of them, as the seasonally occu ring eastward flow at the equator (Puls, 1895), were all h forgotten, until, almost 70 years later, renewed effort wa directed toward a better understanding of this little know area (Schott, 1931; Cromwell, Montgomery and Stroup 1954; Reid, 1959; Wooster, 1959; Knauss, 1960, 1961 Bjerknes, 1961; Wooster and Cromwell, 1958; Wooster an Gilmartin, MS). The present knowledge of the surface cu rents, according to the above mentioned authors, can be sum marized as follows: (a) there are two permanent westwar setting currents, the North Equatorial Current and the Sout Equatorial Current, and two permanent northward settin currents, the Peru Current and the Colombia Current; (b there are three seasonally occurring eastward setting counte currents, the North Equatorial Countercurrent, the equato ial eastward current, and the South Equatorial Counte current. The first countercurrent in the region considered occurs during the northern hemisphere summer and fal the second is found only in the northern hemisphere spring and the third one has been reported only once, in Novembe Several attempts have been made to explain the observe currents theoretically. Linearized equations for steady motio were used by Sverdrup (1947), Reid (1948), Shtokma (1948), Yoshida (1959) and Arthur (1960). Nonlinea equations for steady motion were applied by Fofonof (1954), Charney (1960), Veronis (1960), and Hidak (1961). Most of the authors, however, considered co ditions west of the Galapagos Islands.

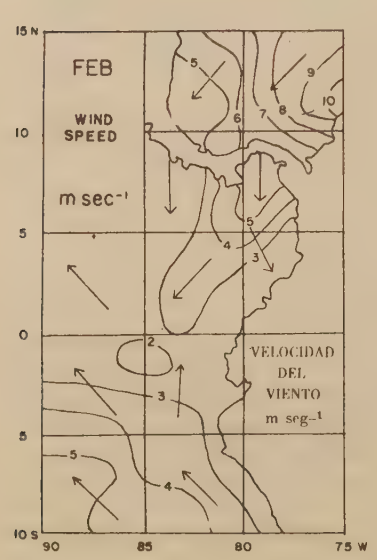
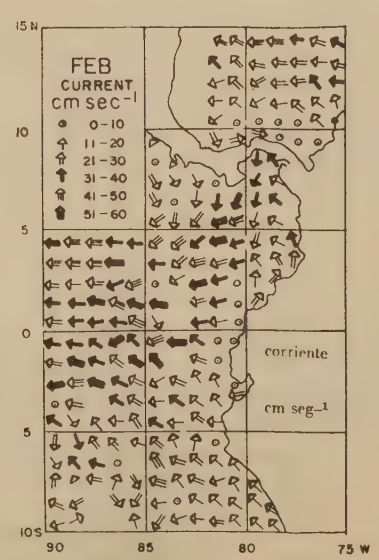


Fig. 1. Corrientes de deriva de barco, vientos y temperaturas de la superficie del mar en el Pacífico ecuatorial oriental en Febrero (U. S. Hydrographic Office 1947 e inéditos).



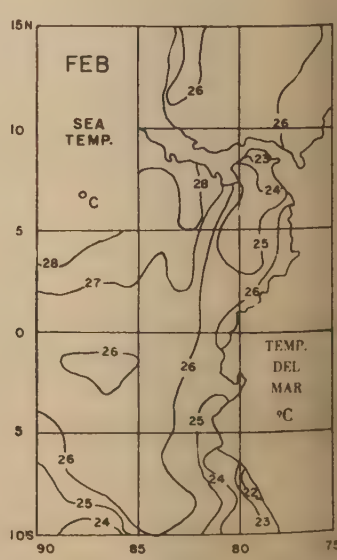
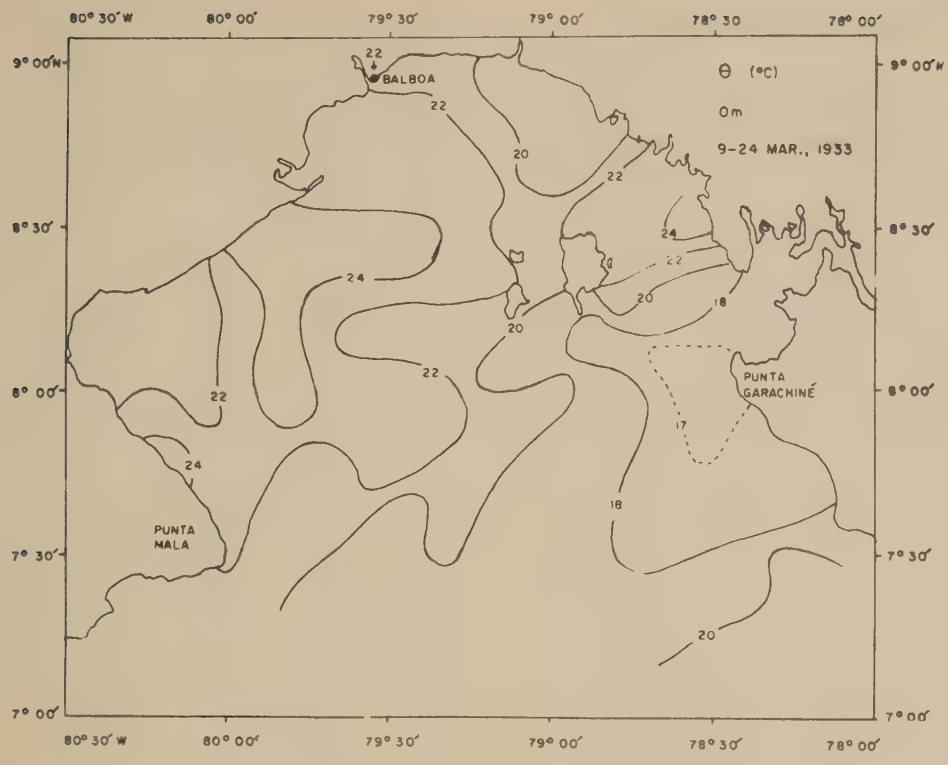


Fig. 1. Ship drift currents, winds and sea surface temperatures in the eastern equatorial Pacific in February (U. S. Hydrographic Office 1947 and unpublished).



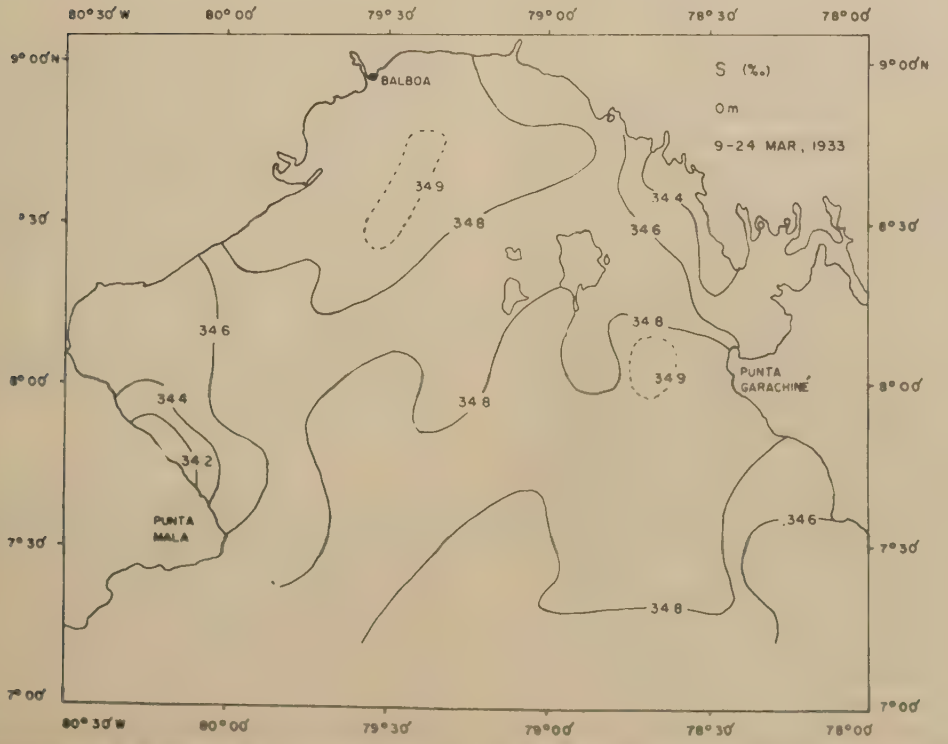


Fig. 2. Temperaturas de la superficie del mar y salinidades en el Golfo de Panamá durante un mes de surgencia (según Fleming, 1934).

Fig. 2. Sea surface temperatures and salinities in the Gulf of Panama during an upwelling month (after Fleming, 1934).

RASGOS PRINCIPALES DURANTE EL INVIERNO DEL HEMISFERIO NORTE (Fig. 1)

En la parte noreste de la región, los alisios del NE del Caribe cruzan el angosto Istmo de Panamá y se extienden varios cientos de kilómetros hacia el sur sin pasar del ecuador. Estos vientos dan origen a una corriente superficial estable relativamente fuerte que va al sur y suroeste y causan fuerte surgencia y mezcla en el Golfo de Panamá (Fig. 2). Es interesante notar que las más bajas temperaturas en esa área no ocurren en el fondo del Golfo, sino un poco al suroeste. El centro del agua fría pareció estar alrededor de la Punta Garachiné en 1933.

Cerca del ecuador los vientos son bastante débiles y soplan predominantemente desde una dirección sureste. Al este de las Islas Galápagos (longitud 90° W), las corrientes superficiales son fuertes y van directamente al oeste. Al oeste de dichas islas las corrientes se hacen más débiles y más variables en dirección (U. S. Hydrographic Office, 1947); ocasionalmente, cuando los vientos son muy débiles, pueden hasta invertirse y circular al este. Una vívida descripción del último fenómeno fue dada por Puls (1895), quien escribió (en traducción): "Otro fenómeno importante y particularmente notable... es la *contracorriente* encontrada casi todos los años cerca del ecuador y al oeste de las Islas Galápagos... Esta contracorriente se observa entre las longitudes 110° W y 90° W y ocurre al mismo tiempo *que las... calmas llegan o pasan al sur del ecuador*, lo que sucede generalmente en Marzo o al comenzar Abril, aunque excepcionalmente también al terminar Febrero o comenzar Mayo... La latitud de la corriente que va al este depende de... la de las calmas; algunas veces la corriente que va al este se encuentra entre las latitudes 0° y 2° N y otras veces entre las latitudes 0° y 3° S... en la costa occidental de las Islas Galápagos da vuelta al norte y al sur para unirse a las corrientes que van al oeste... Las temperaturas superficiales del mar dependen de la dirección de la corriente... con corrientes del oeste las isotermas de 26° y aún 25° C se acercan a las Islas Galápagos, con corrientes del este las isotermas de 26° C y 28° C ocurren ahí... Condiciones similares se presentan en el Atlántico cuando las calmas se extienden al ecuador..." Un ejemplo de la velocidad y dirección de las corrientes cerca del ecuador se presenta en la Tabla I. Debe notarse que la corriente ecuatorial que va al este está separada de la Contracorriente Ecuatorial del Norte por una zona de circulación hacia el oeste.

Recientes mediciones de corrientes a lo largo, del ecuador entre las longitudes 140° W y 89° W (Knauss, 1960) indican una fuerte corriente profunda que va hacia el este por debajo del arrastre superficial hacia el oeste. Es muy posible que la corriente descrita por Puls (1895) sea nada más que la corriente profunda que aflora en la superficie del mar, lo que ocurre en las épocas en que la velocidad del viento cae por debajo de cierto valor crítico.

Durante el invierno del hemisferio norte, los alisios del SE están generalmente confinados a latitudes al sur del

MAIN FEATURES DURING THE NORTHERN HEMISPHERE WINTER (Fig. 1)

In the northeastern part of the region, the NE trades from the Caribbean cross the narrow Isthmus of Panama and extend several hundred kilometers to the southward without passing the equator. These winds give rise to a relatively strong south to southwestward setting surface current, and they cause extensive upwelling and mixing in the Gulf of Panama (Fig. 2). It is of interest to note that the lowest temperatures there do not occur at the head of the Gulf, but somewhat to the southwestward. The center of the cold water appeared to be around Punta Garachiné in 1933.

Near the equator the winds are rather weak and blow predominantly from a southeasterly direction. East of the Galapagos Islands (longitude 90° W) the surface currents are strong and flow almost due west. To the west of these islands the currents become weaker, and more variable in direction. (U.S. Hydrographic Office, 1947); occasionally, when the winds are very weak, they may even reverse themselves and flow to the eastward. A vivid description of the latter phenomenon was given by Puls (1895), who wrote (in translation): "Another important and particularly noteworthy phenomenon... is the *countercurrent* found in most years near the equator and to the west of the Galapagos Islands... This countercurrent is observed between longitudes 110° W and 90° W and occurs at such times *when the... doldrums extend to or south of the equator*, which is generally the case in March and early April, exceptionally also in late February or early May... The latitude of the eastward current depends on... that of the doldrums; sometimes the eastward current is found between latitudes 0° and 2° N, sometimes between latitudes 0° and 3° S... on the west coast of the Galapagos Islands it turns to the north and to the south to join the westward flowing currents... The sea surface temperatures depend on the current direction... with westerly currents the 26° C and even 25° C isotherms are near the Galapagos Islands, with easterly currents the 26° C and 28° C isotherms occur there... Similar conditions are present in the Atlantic when the calms extend to the equator..." An example of the speed and direction of currents near the equator is given in Table I. It is noteworthy that the equatorial eastward current is separated from the North Equatorial Countercurrent by a zone of westward flow.

Recent current measurements along the equator between longitudes 140° W and 89° W (Knauss, 1960) have shown a strong eastward setting undercurrent below the westward surface drift. It is quite possible that the current described by Puls (1895) is nothing else but the undercurrent breaking the sea surface, which occurs at such times when the wind speed falls below a certain critical value.

During the northern hemisphere winter the SE trades are mostly confined to latitudes south of the equator. They

TABLA I

Corrientes de deriva de barco experimentadas por la barca "Niágara" en el Pacífico ecuatorial oriental en Abril de 1883 (según Puls, 1895).

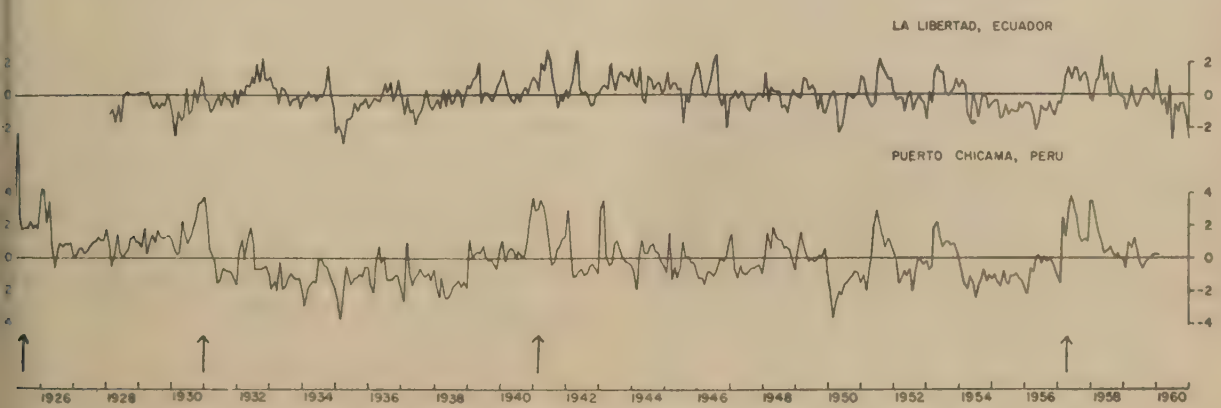
TABLE I

Ship drift currents experienced by the barque "Niagara" in the eastern equatorial Pacific in April 1883 (after Puls, 1895).

Fecha Date	Latitud Latitude	Longitud Longitude	Corriente cm/seg cm/sec	Current grados degrees	
1. IV	5°58′N	96°55′W	49	073	Contracorriente Ecuatorial del Norte / North Equatorial Countercurrent
2. IV	5°30′	96°26′	77	076	
3. IV	4°37′	96°04′	62	115	
4. IV	3°50′	96°33′	63	208	
5. IV	3°30′	97°40′	94	273	Corriente Ecuatorial al oeste / Equatorial westward Current
6. IV	2°59′	97°39′	32	319	
7. IV	2°06′	97°15′	23	186	
8. IV	1°15′	97°03′	88	107	Corriente Ecuatorial al este / Equatorial eastward Current
9. IV	0°48′	96°22′			
10. IV	0°05′S	97°01′	41	115	
11. IV	0°24′	97°30′	4	245	
12. IV	1°05′	98°16′	32	188	
13. IV	2°04′	99°23′	21	180	
14. IV	2°27′	99°44′	176	236	Corriente Ecuatorial del Sur / South Equatorial Current
15. IV	3°51′	101°25′			
16. IV	5°28′	102°53′			
17. IV	7°36′	104°43′	33	281	
18. IV	9°45′	106°53′	38	243	
19. IV	11°26′	108°29′	26	301	

lor, orientan la Corriente del Perú y la Corriente Ecua- del Sur y producen alguna surgencia a lo largo de la s peruana. En algunos inviernos la surgencia frente a falta por completo y es sustituida por el llamado fe- no de "El Niño", caracterizado por temperaturas su- ciales que alcanzan de 4° C a 7° C arriba del prome- por abundante precipitación pluvial (Schott, 1931,

drive the Peru Current and the South Equatorial Current, and they lead to some upwelling along the Peruvian coast. In some winters upwelling off Peru is completely absent, and is replaced by the so-called "El Niño" phenomenon, characterized by surface temperatures 4° C to 7° C above average, and by abundant rainfall (Schott, 1931, 1935). Examples for such large temperature departures are shown



3. Anomalías de temperaturas de la superficie del mar de las ientes medias mensuales de largo término en La Libertad, Ecua- (2°13′S 80°55′W) y Puerto Chicama, Perú (2°42′S 79°27′W). ocasiones en que tuvo lugar "El Niño" se marcan con flecha.

Fig. 3. Sea surface temperature anomalies from the respective long term monthly means at La Libertad, Ecuador (2°13′S 80°55′W) and Puerto Chicama, Peru (7°42′S 79°27′W). The occasions when "El Niño" occurred are marked by an arrow.

1955). Ejemplos de esas grandes divergencias de temperatura se muestran en la Fig. 3 para Puerto Chicama (7° 42′ S; 79° 27′ W) en el centro de la región de surgencias y para La Libertad (2° 13′ S; 80° 55′ W) un poco al norte de la misma región. En un artículo reciente, Bjerknes (1961) observó que "El Niño" es frecuentemente precedido por un debilitamiento de los vientos alisios. Sin embargo, tal debilitamiento de los alisios es también favorable para establecer una circulación superficial hacia el este en el ecuador, como se ha descrito arriba. Es posible, aunque no puede probarse ahora, que en raras circunstancias esta circulación al este en el ecuador, pueda extenderse más allá de las Islas Galápagos y llevar agua cálida a la costa peruana. En favor de tal especulación puede mencionarse como hechos observados que "El Niño" y la circulación ecuatorial hacia el este ocurren casi al mismo tiempo y que totales excesivos de precipitación pluvial en Perú se reflejan también en los registros de las Islas Galápagos (Knoch, 1930), así como en las Islas de la Línea y Marquesas (Schott, 1938).

RASGOS PRINCIPALES DURANTE EL INVIERNO DEL HEMISFERIO SUR (Fig. 4)

Durante el invierno del hemisferio sur, es decir, de Julio a Octubre, los alisios del SE son dominantes dondequiera. Al sur de la latitud 5° S soplan del sureste, pero cerca del ecuador tienen una componente más sureña. Conforme llegan al hemisferio norte se hacen más y más del suroeste y frecuentemente se llaman monsones del SW. En algunos casos, especialmente en Octubre, se ha observado un manifiesto flujo de aire del hemisferio sur que va al Caribe, el cual ocasionalmente se transforma en huracanes en dicha área, como lo ha demostrado Chapel (1927, 1934).

La Corriente del Perú, a pesar de los fuertes vientos sureste en alta mar, es relativamente débil y sólo raras veces alcanza velocidades en exceso de 30 cm/seg^{-1}. Deja la costa cerca de la latitud 4° S para unirse a la Corriente Ecuatorial del Sur. Cerca del ecuador la circulación va generalmente al oeste y casi forma ángulos rectos con la dirección del viento predominante al este de las Islas Galápagos (90° W). En vez de seguir los vientos, parece como si las corrientes circulasen orientándose con las isotermas fuertemente zonales. En una escala más local, existe una circulación hacia el sur a lo largo de la costa de Ecuador, lo que puede explicar la lengua de alta temperatura que se extiende desde el Golfo de Guayaquil al suroeste. Al norte del ecuador el rasgo predominante es la Contracorriente Ecuatorial del Norte que corre entre las latitudes 4° N y 6° N y se extiende a la costa colombiana, donde a su llegada voltea hacia el norte y fluye hacia el Golfo de Panamá.

La surgencia a lo largo de la costa peruana y en la vecindad de las Islas Galápagos es muy fuerte de Junio a Noviembre, como queda evidente en las temperaturas superficiales que se muestran en la Tabla II. Se han observado temperaturas tan bajas como 12° C frente a Perú y como 15° C en las Islas Galápagos.

in Fig. 3 for Puerto Chicama (7° 42′ S; 79° 27′ W) the heart of the upwelling region, and for La Libert (2° 13′ S; 80° 55′ W) just north of the upwelling regi In a recent paper, Bjerknes (1961) observed that "El Ni is frequently preceded by a weakening of the trade wi The weakening of the trades, however, is also favorable establishing surface eastward flow at the equator, as d cribed above. It is possible, though it cannot be proven present, that in unusual circumstances this eastward fl may extend past the Galapagos Islands and carry wa water to the Peruvian coast. The observed facts in fa of this speculation are that "El Niño" and the equator eastward flow occur at about the same time, and t unusual rainfall amounts in Peru are also reflected in records from the Galapagos Islands (Knoch, 1930) a from the Line and Marquesas Islands (Schott, 1938).

MAIN FEATURES DURING THE SOUTHERN HEMISPHERE WINTER (Fig. 4)

During the southern hemisphere winter, that is fr July to October, the SE trades are dominant everywhe South of about latitude 5° S they blow from the southea but near the equator they attain a more southerly co ponent. As they proceed into the northern hemisphere th become more and more southwesterly, and are frequen referred to as the SW monsoon. In some instances, notab in October, there has been observed an organized flow southern hemisphere air into the Carribean which, as sho by Chapel (1927, 1934), occasionally led to hurricane velopment in the latter area.

The Peru Current is, in spite of the strong southeaste winds offshore, relatively weak and attains only rar speeds in excess of 30 cm/sec^{-1}. It leaves the coast about latitude 4° S to join the South Equatorial Curre Near the equator, the flow is predominantly to the we ward and is, east of the Galapagos Islands (90° W), alm at right angles to the prevailing wind direction. Instead following the winds, the currents here appear to flow alo the strong zonally oriented isotherms. On a more local sca there is southward flow along the coast of Ecuador, wh may account for the tongue of high temperatures exte ing southwestward from the Gulf of Guayaquil. North the equator, the predominant feature is the North Equat ial Countercurrent, which flows between latitudes 4° N a 6° N and extends to the Colombian coast. Upon reachi the coast, it turns to the northward and flows toward Gulf of Panama.

Upwelling along the Peruvian coast and in the vicin of the Galapagos Islands is very strong from June to N vember as is evident from the surface temperatures sho in Table II. Temperatures as low as 12° C have be observed off Peru, and as low as 15° C in the Galapa Islands.

TABLA II

TABLE II

Temperaturas medias mensuales (θ) y mínimas medias mensuales (θ min) y máximas (θ max) de la superficie del mar en regiones de surgencia del Pacífico ecuatorial oriental (según U. S. Coast and Geodetic Survey, 1956 e inéditos).

Mean monthly (θ), and mean monthly minimum (θ min) and maximum (θ max) sea surface temperatures in upwelling regions of the eastern equatorial Pacific (after U. S. Coast and Geodetic Survey, 1956 and unpublished).

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Registro Record
Balboa, Panama (8°58'N 79°34'W)														
θ min	(c)	19.4	15.6	17.8	18.9	20.6	25.6	24.4	25.0	25.0	25.0	23.9	2.28	1915-1960
θ	(c)	26.0	24.0	23.3	25.1	27.7	28.4	28.8	28.1	28.2	27.9	27.4	27.1	
θ max	(c)	29.4	29.4	28.4	30.0	31.1	31.7	31.1	31.7	31.1	31.1	32.2	300.	
Isla Naos, Naos Island, Panama (8°55'N 79°34'W)														
θ min	(c)	21.1	20.0	20.0	21.1	23.9	26.7	26.7	26.7	27.2	26.7	25.6	24.4	1950-1959
θ	(c)	26.4	24.7	23.9	25.3	28.1	28.6	28.3	28.2	28.8	28.1	27.7	27.2	
θ max	(c)	30.0	28.9	27.8	28.9	30.0	30.6	30.0	30.0	31.1	30.0	29.4	29.4	
San Cristóbal, Islas Galápagos Galapagos Islands (0°54'S 89°36'W)														
θ min	(c)	17.2	22.8	21.7	20.1	19.0	19.1	18.3	16.9	17.4	15.5	15.4	19.4	1960
θ	(c)	21.2	24.0	24.7	21.8	21.1	19.9	19.7	18.5	19.3	18.3	18.7	21.1	
θ max	(c)	23.1	25.1	27.1	24.6	22.8	21.3	21.7	20.0	21.2	22.2	21.1	22.6	
Talara, Perú (4°35'S 81°17'W)														
θ min	(c)	14.4	16.7	17.2	15.6	15.6	16.1	15.6	15.6	14.4	14.4	13.9	14.4	1944-1959
θ	(c)	21.7	22.8	22.4	20.4	19.1	18.9	18.3	17.8	17.9	17.9	18.1	18.4	
θ max	(c)	27.8	28.3	28.9	26.7	22.8	25.0	23.9	22.2	22.8	24.4	23.3	23.9	
Callao, Perú (12°03'S 77°09'W)														
θ min	(c)	17.2	16.7	17.2	15.0	15.6	14.4	15.0	15.0	15.0	15.0	15.0	15.6	1942-1953
θ	(c)	20.1	21.0	21.2	20.3	18.7	17.4	17.2	17.0	17.1	17.8	18.4	19.2	
θ max	(c)	25.6	27.7	26.1	23.9	22.2	20.0	20.6	20.0	20.0	22.2	21.7	22.2	
Matarani, Perú (17°00'S 72°07'W)														
θ min	(c)	15.0	14.4	14.4	14.4	13.9	13.9	12.2	12.2	12.2	11.7	13.3	13.3	1944-1955
θ	(c)	17.0	16.2	16.3	16.2	15.8	15.4	15.0	14.9	14.5	14.9	15.4	16.3	
θ max	(c)	20.0	18.9	18.9	18.3	18.9	18.9	17.8	17.8	17.2	19.4	17.8	19.4	

ALGUNOS ASPECTOS HIDRODINAMICOS

En lo que sigue se supondrá que las variaciones tempo-
es en densidad y temperatura son tan lentas que pueden
preciarse. Se justifica tal suposición si la escala de tiem-
es del orden de algunos meses o más.

Las ecuaciones de movimiento y continuidad para un
ado permanente pueden escribirse en la siguiente forma

SOME HYDRODYNAMIC ASPECTS

In the following it will be assumed that the time variations of density and velocity are so slow that they can be neglected. The assumption is justified if the time scale is of the order of a few months or more.

The equations of motion and continuity for a steady state can be written in the following form

$$-\rho v (f_z + \zeta_z) + \rho w (f_y + \zeta_y) = -\frac{\partial}{\partial x}\left(p + \frac{\rho}{2} V^2\right) + \frac{1}{2} V^2 \frac{\partial \rho}{\partial x} + \frac{\partial \tau_x}{\partial z}$$

$$+\rho v (f_z + \zeta_z) - \rho w (f_x + \zeta_x) = -\frac{\partial}{\partial y}\left(p + \frac{\rho}{2} V^2\right) + \frac{1}{2} V^2 \frac{\partial \rho}{\partial y} + \frac{\partial \tau_y}{\partial z} \qquad (1)$$

$$0 = -\frac{\partial p}{\partial z} - \rho g$$

$$0 = \frac{\partial \rho u}{\partial x} + \frac{\partial \rho v}{\partial y} + \frac{\partial \rho w}{\partial z}$$

donde x se sitúa al este, y al norte y z arriba, p denota presión, g es gravedad, ρ es densidad, u, v, w son las componentes de velocidad, $V^2 = u^2 + v^2 + w^2$ y τ_x, τ_y son las componentes horizontales de esfuerzo debidas a la tensión vertical. Las componentes de la vorticidad planetaria están dadas por $f_x = 0$, $f_y = 2\omega \cos\varphi$ y $f_z = 2\omega \operatorname{sen}\varphi$, donde ω es la velocidad angular de la rotación terrestre y φ es la latitud. Las componentes de la vorticidad relativa son

where x is toward the east, y is toward the north, and z upward, p denotes pressure, g is gravity, ρ is density, v, w, are the velocity components, $V^2 = u^2 + v^2 + w^2$, a τ_x, τ_y are the horizontal components of stress due to verti shear. The components of the planetary vorticity are giv by $f_x = 0$, $f_y = 2\omega \cos\varphi$ and $f_z = 2\omega \sin\varphi$, where ω is t angular speed of the earth's rotation, and φ is latitude. T components of the relative vorticity are

$$\zeta_x = \frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}\,; \quad \zeta_y = \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}\,; \quad \zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$$

La suma de los vectores $f + \zeta$ es llamada la vorticidad absoluta y la expresión $p + \frac{1}{2}\rho V^2$ frecuentemente se denomina la presión dinámica.

The sum of the vectors $f + \zeta$ is called the absolute v ticity, and the expression $p + \frac{1}{2}\rho V^2$ is frequently referr to as the dynamic pressure.

(A) Condiciones a lo largo del ecuador, entre las Islas Galápagos y 140° W.

Recientes mediciones de corrientes y observaciones hidrográficas de Knauss (1960), entre las longitudes 90° W y 140° W, han mostrado que el flujo es generalmente zonal y que la distribución de corriente y temperatura (densidad) es simétrica respecto al ecuador. Puesto que $f_z = 0$ a lo largo del último y ζ_z llega a cero por efecto de la circulación zonal y de la simetría, la ecuación (1), despreciando el pequeño término que incluye los gradientes de densidad horizontal, indica que

(A) Conditions along the equator between the G lapagos Islands and 140° W.

Recent current measurements and hydrographic o servations by Knauss (1960) between longitudes 90° and 140° W have shown that the flow is mostly zonal, a that the current and temperature (density) distribution symmetrical with respect to the equator. Since $f_z = 0$ alo the latter, and ζ_z becomes zero on account of the symmetr and zonal flow, equation (1) states, upon neglecting t small term involving the horizontal density gradients, tha

$$\rho w\,(f_y + \zeta_y) = -\frac{\partial}{\partial x}\left(p + \frac{\rho}{2} V^2\right) + \frac{\partial \tau_x}{\partial z} \qquad (2$$

En la superficie del mar $w = 0$ y el gradiente de presión dinámica este-oeste queda equilibrado por el gradiente vertical de la componente zonal del esfuerzo de tensión. La magnitud del gradiente de presión dinámica en la superficie, obtenido de observaciones hidrográficas a lo largo del ecuador por la expedición del "Dolphin", es aproximadamente $5 \cdot 10^{-5}$ dinas/cm^{-3}. Si $\frac{\partial \tau_x}{\partial_z}$ puede ser aproximado por τ_{xo}/H, donde τ_{xo} es el esfuerzo del viento en la superficie del mar y H la profundidad del núcleo de la corriente profunda, entonces con $H = 50$ m aproximadamente, el esfuerzo del viento necesario para balancear el gradiente de presión dinámica es más o menos de 0.25 dinas/cm^{-2}, que corresponde a una velocidad del viento de unos 2.8 m/seg^{-1}. Si la velocidad del viento es mucho menor que este valor crítico, la circulación a lo largo del ecuador quedará determinada por la ecuación de Bernoulli y la circulación superficial irá al este, porque el nivel del mar decrece de oeste a este, a lo menos según puede concluirse de alturas dinámicas ($^{\circ}/_{1000}$ db). Sin embargo, como se indicó arriba, un viento muy ligero es suficiente para neutralizar la pendiente superficial y por ello, la circulación superficial al este debe ser un fenómeno relativamente infrecuente en el ecuador.

At the sea surface $w = 0$, and the east-west dynamic pre sure gradient is balanced by the vertical gradient of t zonal component of the shearing stress. The magnitude the dynamic pressure gradient at the surface, obtaine from hydrographic observations along the equator by t "Dolphin" expedition, is approximately $5 \cdot 10^{-5}$ dynes/cm Provided $\frac{\partial \tau_x}{\partial_z}$ can be approximated by τ_{xo}/H, where τ_{xo} the wind stress at the sea surface, and H is the depth the core of the undercurrent, then, with $H = 50$ m a proximately, the wind stress necessary to balance the d namic pressure gradient is roughly 0.25 dynes/cm^{-2}. Th corresponds to a wind speed of about 2.8 m/sec^{-1}. If t wind speed is much less than this critical value, the flo along the equator will be determined by the Bernoul equation, and the surface flow will be to the eastward, b cause the sea level decreases from west to east, at least a far as it can be concluded from dynamic heights ($^{\circ}/_{1000}$ db) As indicated above, however, a very slight wind is sufficien to balance the surface slope, so that the surface eastwar flow must be a relatively infrequent phenomenon at th equator.

CONDICIONES A LO LARGO DEL ECUADOR ENTRE LAS ISLAS GALÁPAGOS Y AMÉRICA DEL SUR.

El rasgo más notable de las corrientes superficiales ste de las Islas Galápagos es que circulan aproximada- te en ángulos rectos con la dirección del viento predo- ante y que parecen seguir las isotermas. En vista de la nda de las ecuaciones de (1), ello sugiere que puede tir el siguiente equilibrio en la superficie del mar (des- iando el pequeño término que incluye el gradiente de idad meridional y notando que $w = f_z = 0$)

$$[\rho u\, \zeta_z]_0 = -\left[\frac{\partial p}{\partial y}\right]_0 - \left[\frac{1}{2}\frac{\partial \rho V^2}{\partial y}\right]_0 + \frac{\tau_{yo}}{H} \qquad (3)$$

í el índice cero señala que los términos deben calcularse a superficie del mar, en tanto que H denota la profun- d en el termoclinal donde se supone que desaparece el erzo del viento. La ecuación (3) será usada para estimar den de magnitud de la componente vertical de vortici- relativa en el ecuador. Haciendo uso de observaciones ográficas y meteorológicas en la longitud 83° 50′ W y as latitudes 0° 58′ N, 0° 00′ y 0° 58′ S (Expedición ropic, 1955, inédito), se encuentra que el gradiente de eratura es $+ 3{\cdot}10^{-4}$ g/cm^{-2}/seg^{-2} y que el término del erzo del viento es $1.6{\cdot}10^{-4}$ g/cm^{-2}/seg^{-2}. El gradiente de gía cinética en la región considerada (Figs. 1 y 4) es $0{\cdot}10^{-4}$ g/cm^{-2}/seg^{-2}. Tomando $\rho = 1$ g/cm^{-3} y u = – 30 eg^{-1}, se obtiene para la componente vertical de la vor- iad relativa en el ecuador un valor de $+ 3{\cdot}10^{-6}$/seg^{-1}. álculo mencionado es bastante burdo, pero sirve para ar que los términos que incluyen el gradiente de ener-

(B) CONDITIONS ALONG THE EQUATOR BETWEEN THE GALAPAGOS ISLANDS AND SOUTH AMERICA.

The outstanding feature of the surface currents east of the Galapagos Islands is that they flow approximately at right angles to the prevailing wind direction, and that they seem to follow the isotherms. This suggests, in view of the second of equations (1), that the following balance might exist at the sea surface (neglecting the small term involving the meridional density gradient, and noting that $w = f_z = 0$):

Here the subscript zero indicates that the terms are to be evaluated at the sea surface, and H denotes the depth to the thermocline where the wind stress is supposed to vanish. Equation (3) will be used to estimate the order of magnitude of the vertical component of relative vorticity at the equator. Making use of hydrographic and meteorological observations at longitude 83° 50′ W and latitudes 0° 58′ N, 0° 00′, 0° 58′ S (Eastropic Expedition, 1955, unpublished), one finds that the pressure gradient is $+ 3{\cdot}10^{-4}$ g/cm^{-2}/sec^{-2}, and that the wind stress term is $1.6{\cdot}10^{-4}$ g/cm^{-2}/sec^{-2}. The kinetic energy gradient in the region considered (Figs. 1 and 4) is $-0.5{\cdot}10^{-4}$ g/cm^{-2}/sec^{-2}. Taking $\rho = 1$ g/cm^{-3} and u = –.30 cm/sec^{-1}, one obtains for the vertical component of the relative vorticity at the equator a value of $+ 3{\cdot}10^{-6}$/sec^{-1}. The above calculation is quite rough, but it serves to illustrate that the terms involving the kinetic energy gradient and the relative vorticity are comparable to the

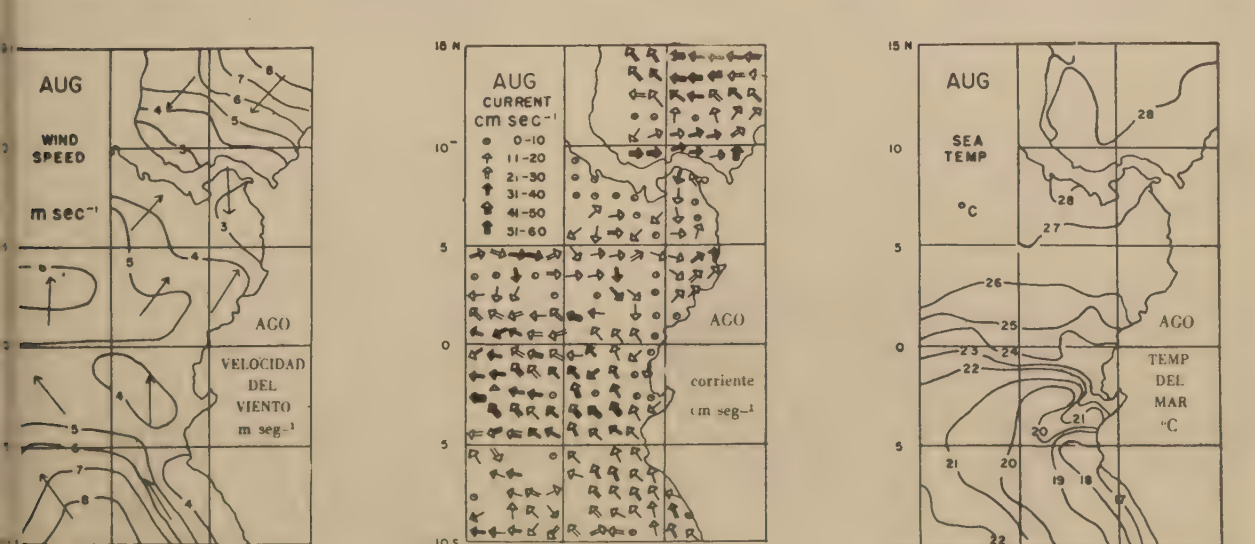


Fig. 4. Corrientes de deriva de barco, vientos y temperaturas de superficie del mar en el Pacífico ecuatorial oriental en Agosto (U. S. Hydrographic Office 1947 e inéditos).

Fig. 4. Ship drift currents, winds and sea surface temperatures in the eastern equatorial Pacific in August (U. S. Hydrographic Office 1947 and unpublished).

gía cinética y la vorticidad relativa son comparables a los términos del gradiente de presión y del esfuerzo del viento en la cercanía del ecuador.

(C) El campo de dirección de la corriente de transporte de masa total en el Pacífico Tropical Oriental.

La función de dirección de la corriente de transporte de masa total puede obtenerse, en una primera aproximación, diferenciando en cruz las primeras dos ecuaciones de (1), substrayendo y despreciando los términos no-lineales e integrando desde el fondo – D hasta la superficie del mar. El resultado es

$$\beta \frac{\partial \psi}{\partial x} = \frac{\partial \tau_y}{\partial x} - \frac{\partial \tau_x}{\partial y}$$

donde $\beta = 2\,\omega \cos \varphi / R$ (R es el radio de la tierra, φ es la latitud) es el cambio del parámetro de Coriolis con la latitud, que se supone aquí constante.

pressure gradient and wind stress terms in the vicinity the equator.

(C) The total mass transport stream line field the Eastern Tropical Pacific.

The stream line function for the total mass transp can be obtained, to a first approximation, by cross d ferentiating the first two of equations (1), subtracti neglecting the nonlinear terms, and integrating from the b tom – D, to the sea surface. The result is:

where $\beta = 2\,\omega \cos \varphi / R$ (R is the earth radius, φ is latitud is the change of the Coriolis parameter with lattiude, h assumed constant.

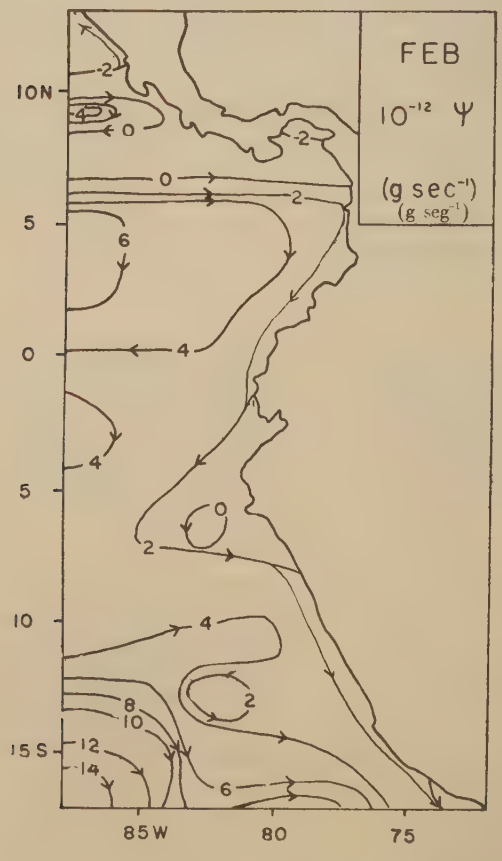


Fig. 5. Direcciones de corrientes de transporte de masa total computadas de datos de viento en cuadrados de dos grados de latitud y longitud (U. S. Hydrographic Office, inéditos). Las flechas indican la dirección de la corriente.

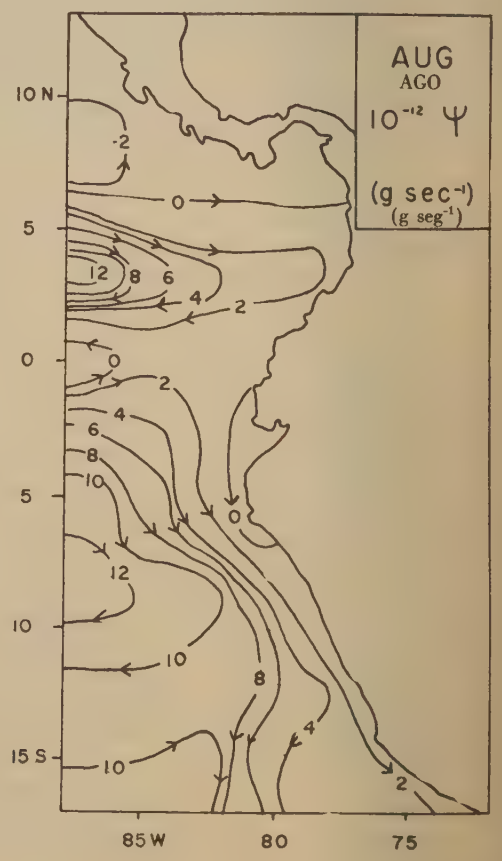


Fig. 5. Total mass transport stream lines computed from wind data in two degree squares of latitude and longitude (U. S. Hydrographic Office, unpublished). The arrows indicate the direction of flow.

La función lineal de la corriente, ψ, se define por

$$\frac{\partial \psi}{\partial x} = \int_{-D}^{0} \rho v dz,$$

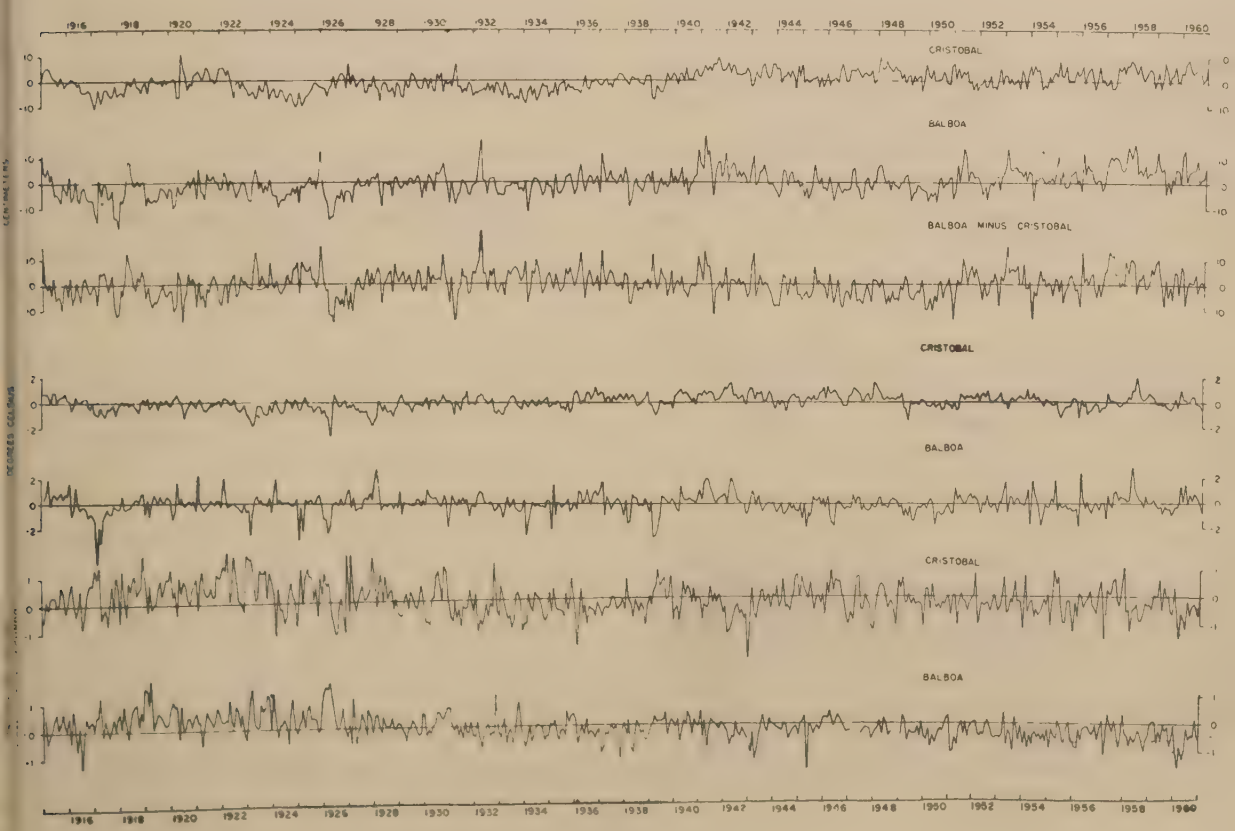
y ha sido usada por Sverdrup (1947) y

noff (1955-61). Integrando la ecuación (4) respecto a tomando la función de corriente como cero en la costa, lega al campo de direcciones de corriente en la Fig. 5. computaciones se basaron en observaciones del viento uadrados de dos grados de longitud y latitud (U. S. Hygraphic Office, inédito), lo que representa una mejoría e datos disponibles previamente en cuadrados de cinco dos (Hidaka, 1958).

Algunos rasgos interesantes destacan en la Fig. 5: (1) el sporte de masa total a lo largo de la costa peruana va ur, en oposición a la dirección predominante de las contes superficiales, lo cual parece estar de acuerdo con iciones recientes de corrientes por Wooster y Gilmartin S); (2) el transporte de masa total entre las latitudes N y 6° N va al este tanto en Febrero como en Agosto, ontraste con las condiciones superficiales, donde la circución hacia el este no tiene lugar durante el invierno del isferio norte; (3) el transporte de masa total entre las

The stream line function, ψ, is defined by $\frac{\partial \psi}{\partial x} = \int_{-D}^{0} \rho v dz$, and has been used by Sverdrup (1947) and Fofonoff (1955-61). Integrating equation (4) with respect to x, and taking the stream function to be zero at the coast, it leads to the stream line field shown in Fig. 5. The computations were based upon wind observations in two degree squares of latitude and longitude (U.S. Hydrographic Office, unpublished), which represents an improvement over the previously available data in five degree squares (Hidaka, 1958).

Several interesting features stand out in Fig. 5: (1) the total mass transport along the Peruvian coast is southward, opposite to the prevailing direction of the surface currents. This seems to be in agreement with recent current measurements by Wooster and Gilmartin (MS); (2) the total mass transport between latitudes 4° N and 6° N is to the eastward in both February and August, in contrast to surface conditions, where eastward flow does not occur in the northern hemisphere winter; (3) the total mass transport between latitudes 13° S and 15° S is to the east, which agrees



g. 6. Nivel del mar, temperaturas de la superficie del mar y omalías del viento de las correspondientes medias mensuales de go término en Balboa y Cristóbal, Panamá (Registros de datos proporcionados por la Compañía del Canal de Panamá).

Fig. 6. Sea level, sea surface temperature and wind anomalies from the respective long term monthly means at Balboa and Cristobal, Panama (Data records furnished by the Panama Canal Company).

latitudes 13° S y 15° S va al este, lo cual está de acuerdo en general con los cálculos geostróficos de Reid (1959); (4) el cambio del campo de direcciones de corriente entre Febrero y Agosto es considerable. Todo eso indicaría, que el océano responde barotrópicamente a cambios en el remolino del esfuerzo del viento. El tiempo de respuesta barotrópica es del orden de pocos meses (Sarkisyan, 1957). Sin embargo, una respuesta baroclínica es mucho más lenta (Welander, 1959).

ALGUNOS ASPECTOS ESTADISTICOS DE LA SURGENCIA EN EL GOLFO DE PANAMA

Uno de los rasgos más notables en el Golfo de Panamá es la aparición de bajas temperaturas en la superficie del mar durante períodos de fuertes vientos nortes (Schott, 1931; Fleming 1934, 1941; Schaefer, Bishop y Howard, 1958). Ya que se han obtenido registros continuos de temperatura superficial del mar, nivel del mar y viento por la Compañía del Canal de Panamá por más de cincuenta años, es interesante saber cómo están relacionadas estas variables entre sí, en sentido estadístico. En la Fig. 6 se muestran las desviaciones de las mencionadas variables respecto a los correspondientes promedios mensuales para el período 1915 a 1960. Puede verse que mientras hay alguna elevación en el nivel del mar y disminución en la velocidad del viento, las anomalías de la temperatura superficial del mar fluctuaron alrededor de un promedio más o menos estacionario.

La relación estadística entre registros cuyas variaciones estacionales fueron eliminadas se determinó por análisis espectral (Munk, Snodgrass y Tucker, 1958). Las densidades espectrales de potencia se muestran en la Fig. 7 para un ran-

roughly with geostrophic calculations by Reid (1959); (4) the change of stream line field from February to August considerable. All this would indicate, that the ocean re ponds barotropically to changes in the curl of the wi stress. The barotropic response time is in the order of fe months (Sarkisyan, 1957). A baroclinic response howeve is much slower (Welander, 1959).

SOME STATISTICAL ASPECTS OF UPWELLING IN THE GULF OF PANAMA

One of the outstanding features in the Gulf of Panam is the occurrence of low temperatures at the sea surfa during periods of strong northerly wind (Schott, 193 Fleming, 1934, 1941; Schaefer, Bishop and Howard, 1958 Since continuous records of sea surface temperature, wi and sea level have been kept by the Panama Canal Compan for over fifty years, it is of interest to note how these va iables are related to each other in a statistical sense. Fig. 6 are shown the deviations of the above mentione variables from the respective monthly means over the perio 1915 to 1960. It is seen that while there was some ri in sea level and a decrease in wind speed, the sea surfa temperature anomalies fluctuated around a more or le stationary mean.

The statistical relation among records from which th seasonal variation was eliminated was determined by spectra analysis (Munk, Snodgrass and Tucker, 1958). The powe spectral densities are illustrated in Fig. 7 for the frequenc

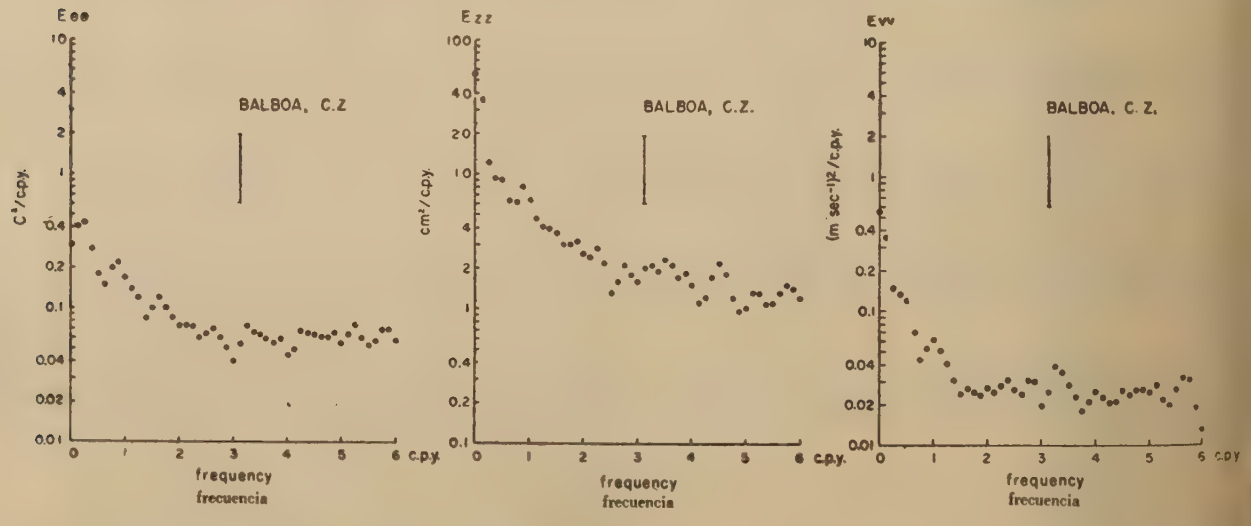
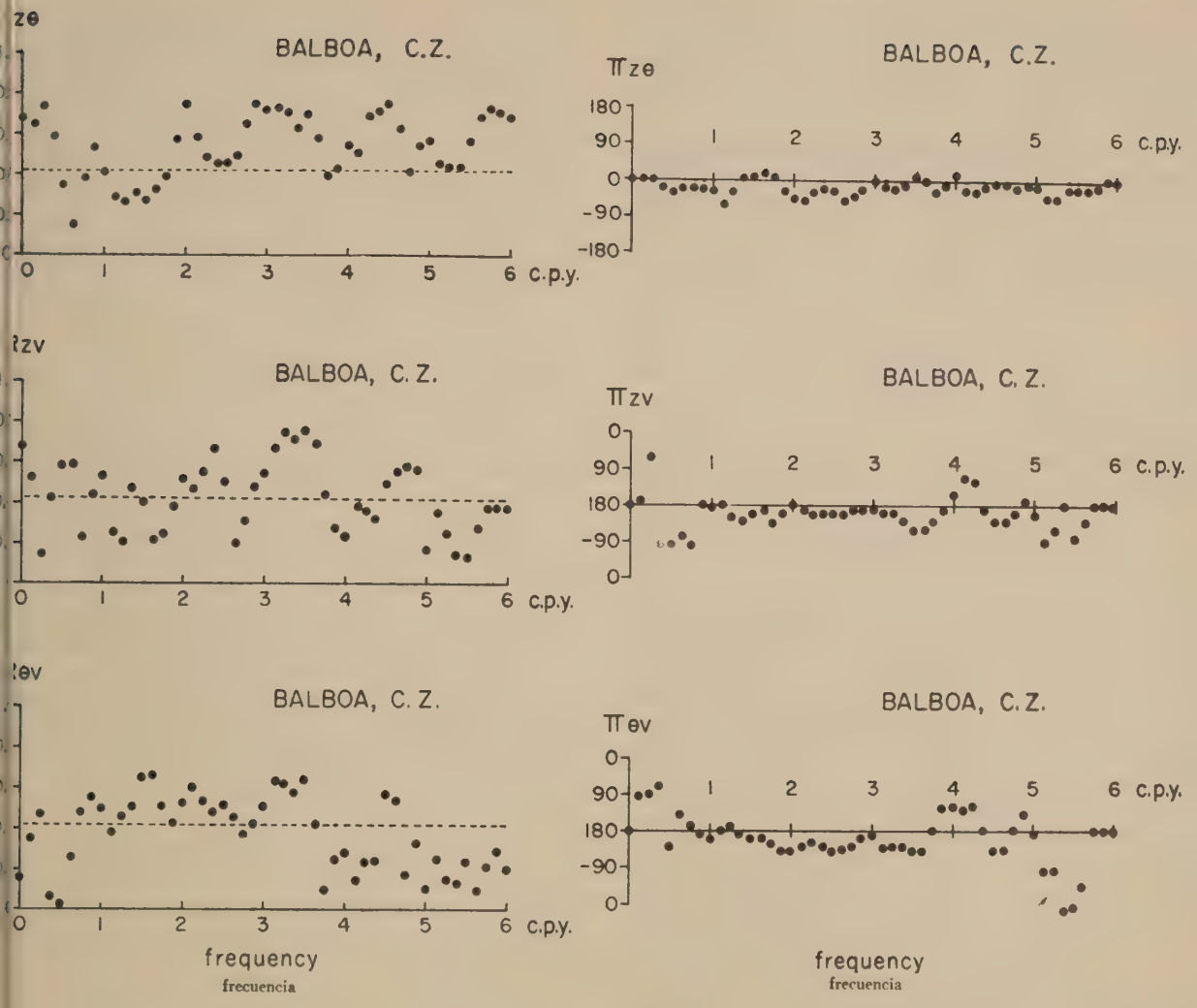


Fig. 7. Densidades espectrales de potencia de nivel del mar (E_{zz}), temperaturas de la superficie del mar ($E_{\theta\theta}$) y anomalías de viento (E_{vv}). La línea vertical indica los límites del 95% de confianza.

Fig. 7. Power spectral densities of sea level (E_{zz}), sea surface temperature ($E_{\theta\theta}$) and wind (E_{vv}) anomalies. The vertical line indicates the 95% confidence limits.



ig. 8. Coherencia (R) y fase ($_\pi$) entre el nivel del mar y la mperatura de la superficie del mar ($z\theta$), nivel del mar y viento v) y temperaturas de la superficie del mar y anomalías de ento (θv). La línea horizontal indica los límites aproximados de 95% de confianza.

Fig. 8. Coherence (R) and phase ($_\pi$) between sea level and sea surface temperature ($z\theta$), sea level and wind (zv) and sea surface temperature and wind (θv) anomalies. The horizontal line indicates the approximate 95% confidence limits.

e frecuencia entre 0 y 6 ciclos por año (c.p.a.). La línea cal se refiere a los límites de 95% de confianza del ctro. Puede verse que la potencia decrece rápidamente e 0 c.p.a. hasta cerca de 2 c.p.a. y que queda casi cons- desde esa cifra hasta 6 c.p.a. La potencia total conte- en el espectro a nivel del mar sube a 25.2 (cm) ^{2} ., en el espectro de temperatura superficial del mar a C ^{2} c.p.a. y en el espectro del viento a 0.29 (m seg^{-1})^2. ay picos significantes en los espectros, lo que indica la ncia de periodicidades en los registros de anomalías.

a coherencia entre pares de variables se muestra en la 8, donde la línea horizontal discontinua se refiere a los es aproximados de 95% de confianza. Existe una buena rencia entre el nivel del mar y la temperatura super- l del mar para frecuencias entre 2 c.p.a. y 6 c.p.a. y la

range between 0 and 6 cycles per year (c.p.y.). The vertical line refers to 95% confidence limits of the spectra. It is seen that the power decreases rapidly from 0 c.p.y. to about 2 c.p.y., and that it remains rather constant from there to 6 c.p.y. The total power contained in the sea level spectrum amounts to 25.2 (cm)^2 c.p.y., in the sea surface temperature spectrum to 0.62° C^2/c.p.y. and in the wind spectrum to 0.29 (m sec^{-1})^2. There are no significant peaks in the spectra, indicating the absense of periodicities from the anomaly records.

The coherence between pairs of variables is shown in Fig. 8, where the dashed horizontal line refers to the approximate 95% confidence limits. There is good coherence between sea level and sea surface temperature for frequencies between 2 c.p.y. and 6 c.p.y., and the phase of

fase de cero grados aproximadamente indica que las variables se relacionan entre sí directa e instantáneamente. La coherencia entre el nivel del mar y el viento es moderadamente alta para frecuencias entre 2 c.p.a. y 3.5 c.p.a. La fase de cerca de −150 grados sugiere que existe una relación inversa entre las variables, ya que el viento precede ligeramente al nivel del mar. La coherencia entre la temperatura del mar y la velocidad del viento es significante para frecuencias entre 1 c.p.a. y 3.5 c.p.a. Como puede esperarse, estas variables están inversamente relacionadas entre sí. Hay un pequeño retardo de la temperatura respecto al viento.

CONCLUSIONES

Un notable rasgo de la circulación a lo largo del ecuador es la ocasional contracorriente superficial al oeste de las Islas Galápagos (Puls, 1895). Solamente tiene lugar cuando el esfuerzo del viento cae por debajo de cierto valor crítico y parece representar la manifestación superficial de una corriente ecuatorial profunda que va al este. El valor crítico del esfuerzo del viento, obtenido por consideraciones hidrodinámicas, es de 0.25 dinas/cm^{-2} y corresponde a una velocidad del viento de unos 2.8 m/seg^{-1}. Vientos más débiles son incapaces de balancear el gradiente de presión dinámica del oeste al este y puede ocurrir un flujo hacia abajo. Posiblemente una extensión de esta corriente más allá de las Islas Galápagos, hacia la costa sudamericana, origina el fenómeno de "El Niño" frente a Perú.

Al este de las Islas Galápagos las corrientes de la circulación ecuatorial forman frecuentemente ángulos rectos con la dirección del viento predominante y parecen seguir las isotermas superficiales. Se demostró que en esta parte del océano, el término no-lineal $\rho u \zeta_z$ y $\frac{1}{2}\frac{\partial x}{\partial y}\rho V^2$ son bastante comparables a los términos que incluyen el gradiente de presión de norte a sur y el esfuerzo del viento y que la componente vertical de la vorticidad relativa 3_z es positiva (cerca de $3 \cdot 10^{-6}$/seg^{-1}).

Un examen de las líneas de corriente del transporte de masa total, computadas por observaciones del viento en cuadrados de dos grados de latitud y longitud, mostró que la circulación a lo largo de la costa peruana va hacia el sur, en oposición a la dirección de las corrientes superficiales. Entre las latitudes 4° N y 6° N la circulación va hacia el este, tanto en verano como en invierno, en contraste con las condiciones superficiales donde la circulación hacia el este sólo tiene lugar durante el verano del hemisferio norte.

Un análisis estadístico de largos registros de temperatura superficial del mar, nivel del mar y viento en el Golfo de Panamá mostró que la temperatura y el nivel del mar son inversamente proporcionales al viento, como es típico de las regiones de surgencia. El espectro de potencia indicó que casi todo el valor de estas variables está concentrado en las bajas frecuencias y que no hay periodicidades significantes en los espectros.

approximately zero degrees indicates that the variables
related to each other directly and instantaneously. The
herence between sea level and wind is moderately high
frequencies between 2 c.p.y. and 3.5 c.p.y. The phase
about −150 degrees suggests that there exists an inve
relation between the variables, with the wind slightly le
ing sea level. The coherence between sea temperature a
wind speed is significant for frequencies between ab
1 c.p.y. to 3.5 c.p.y. As can be expected, these variables
related inversely to one another. There is a slight lag of
temperature behind the wind.

CONCLUSIONS

A noteworthy feature of the flow along the equator
the occasional surface countercurrent to the west of the
lapagos Islands (Puls, 1895). It occurs only when the w
stress falls below a certain critical value, and appears
represent the surface manifestation of the eastward flow
equatorial undercurrent. The critical value of the wi
stress, obtained from hydrodynamic considerations, is ab
0.25 dynes/cm^{-2}, and corresponds to a wind speed of ab
2.8 m/sec^{-1}. Weaker winds are unable to balance the w
to east dynamic pressure gradient, and downslope flow
likely to occur. An extension of this current past the Ga
pagos Islands to the South American coast could conce
ably lead to "El Niño" phenomenon off Peru.

East of the Galapagos Islands the currents at the equa
flow are frequently at right angles to the prevailing wi
direction, and seem to follow the surface isotherms, It w
shown that in this part of the ocean the non-linear te
$\rho u \zeta_z$ and $\frac{1}{2}\frac{\partial x}{\partial y}\rho V^2$ are quite comparable to the terms invo
ing the north to south pressure gradient and the wind stre
and that the vertical component of the relative vorticity,
is positive (about $3 \cdot 10^{-6}$/sec^{-1}).

An examination of the total mass transport stream li
computed from wind observations in two degree squares
latitude and longitude showed that the flow along the P
uvian coast is to the south ward, opposite to the direct
of the surface currents. Between latitudes 4° N and 6°
the flow is to the eastward in both summer and winter
contrast to surface conditions, where eastward flow occ
only during northern hemisphere summer.

A statistical analysis of long sea surface temperatu
sea level and wind records in the Gulf of Panama show
that temperature and sea level are related inversely to
wind, as is typical of upwelling regions. The power spec
indicated that most of the power of these variables is co
centrated at low frequencies, and that there are no signif
ant periodicities in the spectra.

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39685

XII. United States Research in the Convention Area during 1960

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Market sampling of the major species landed from the Convention Area continued at all important ports. Research samples of bottom fish, samples of bottom fauna, and hydrographic observations were made on eight cruises of the research vessel *Delaware* and on two cruises of a charter vessel.

Haddock (*Melanogrammus aeglefinus* (L.))

The fishery. The abundance of haddock on Georges Bank and the landings in 1960 were higher than in the previous two years (Table 1). This was due largely to the abundance of the 1958 year-class which contributed heavily to the catch as 2-year-old scrod. Scrod comprised about 50% of the landings in 1960 compared to about 47% in 1959. The increase in landings occurred in spite of a drop in effort. The age composition of the landings for the last three years is shown in Figure 1.

The fishery should improve in 1961 as the fish in the 1958 year-class grow to larger size. Fall survey cruises designed to assess the abundance of pre-recruit haddock showed low numbers of young-of-the-year (1960 year-class). Thus, it is expected that scrod landings will drop in 1962, which may possibly have an effect on total landings, depending upon the abundance of the 1958 year-class which will then be four years old.

Tagging. Tagging records were analyzed to determine the effect of the condition of the fish at time of tagging upon numbers of returns.

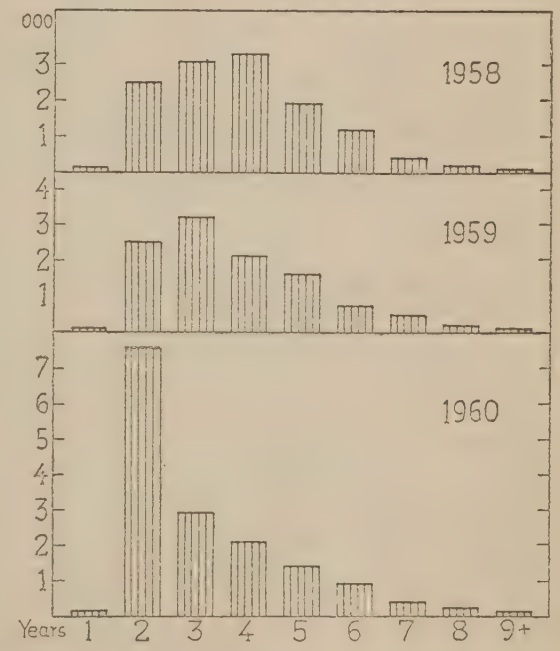

Fig. 1. Age composition of Georges Bank haddock, 1958-60. Catch per day (thousands of fish) of ages 1 to 9 +; for 1960 only the first nine months.

TABLE 1. Trends in the Georges Bank haddock fishery.

Year	Landings (thousands of pounds)	Days fished	Average Landings per day (pounds)
1951	91,508	6,490	14,098
1952	83,645	5,933	14,098
1953	69,476	6,511	10,671
1954	89,710	5,807	15,448
1955	78,942	5,059	15,603
1956	94,505	6,794	13,910
1957	89,251	8,050	11,087
1958	68,655	7,836	8,761
1959	69,350	9,432	7,353
1960	79,470	7,669	10,362

Preliminary results indicated fewer recaptures of fish with evidence of scale loss or subcutaneous bleeding as compared with undamaged fish at time of tagging.

Another analysis was made to compare percentage return of different types of tags. Percentage returns were twice as high for spaghetti tags as for Petersen disc tags whether inserted in the dorsum or the operculum. These tagging experiments were conducted in Divisions 4X and 5Z.

Age Determination. Age analysis of special collections of scales and otoliths from groundfish surveys and from routine port collections continues for comparative age and growth studies.

A critical review of the scale method for haddock age determinations was completed.

Cod (*Gadus morhua* L.)

The Fishery. Total U.S. cod landings in 1960 were down about 4 million pounds from the 1959 landings, bringing the figure near the 1957 level of 32 million pounds.

Research. In 1959, we reported a study in which drift bottles were dropped from U.S. Navy airships (blimps) in the offing of New Jersey. Bottle recoveries to date have shown no clear pattern of surface currents in the area. Most of the bottles were recovered within about 5 miles or less of the drop station, but there have been three long-distance recoveries. One bottle stranded in the Azores, one in Bermuda, and one in Ireland.

U.S. cod studies were started only a few years ago and on a limited basis. The initial program comprised studies of the number of stocks, migrations, and growth rates. We have now started a study of the age composition of cod in Subarea 5. These data are essential to population studies of the fish in this subarea and should provide vital information on the effects of fishing.

Silver Hake (*Merluccius bilinearis* (Mitchill)

The Fishery. Landings of silver hake for 1960 from Subarea 5 decreased slightly from the previous year. Landings and catch per day of small and medium otter trawlers fishing out of Gloucester, Massachusetts, are shown in Table 2. The year 1957 was a peak year for both landings and abundance. The abundance figures show an irregular decline since then, but landings at Gloucester are still higher than in 1956. An analysis of the catch per day for each fishing ground showed some decrease in abundance on all grounds fished.

Research. Survey cruises were conducted to determine the winter distribution of the silver hake. The largest number was caught in depths greater than 100 fathoms, in temperatures ranging from 44°F to 52°F (6.7°-11.1°C) in the general area between Cape Cod and Cape Hatteras.

Redfish (*Sebastes*)

The Fishery. The U.S. redfish landings in 1960 were about 139.5 million pounds, an increase of approximately 2.5 million pounds over the 1959 value, but well below the annual average of 178 million for the fishery since 1946. About 30 million pounds were landed from the Gulf of Maine, 71 million from the Nova Scotian banks, 31 million from the Grand Bank, and 7 million from the Gulf of St. Lawrence.

TABLE 2. Trends in the silver hake fishery Subarea 5. (Data for Gloucester Massachusetts only).

Year	Landings Subarea 5 (thousands of pounds)	Catch per day OTS[1]	Catch per day OTM[2]
1956	90,090	25.8	58.9
1957	126,312	44.0	69.6
1958	106,650	33.5	47.6
1959	110,144	35.8	51.0
1960	104,785	32.9	39.9

[1] Otter trawl — small [2] Otter trawl — medium.

Preliminary estimates for 1960 show the redfish catch per unit of effort to be approximately equal to, or slightly higher than, the 1959 values on all grounds fished by U.S. vessels.

Research. Studies are in progress on the definition of redfish stocks in the Gulf of Maine, directed toward an understanding of the population dynamics of this species. Records of

TABLE 3. Trends in the redfish fishery.

Year	Landings (thousands of pounds)	Calculated fishing effort (days fished)	Catch per day (thousands of pounds)
		Gulf of St. Lawrence	
1951	8,517	353.1	24.12
52	9,949	463.4	21.47
53	16,026	681.7	23.51
54	37,981	1517.4	25.03
55	76,586	2397.1	31.95
56	54,729	2024.0	27.04
57	40,385	1960.4	20.60
58	16,611	843.6	19.69
59	11,489	551.6	20.83
1960	7,000*	—	—
		Grand Bank	
1951	29,900	445.5	67.12
52	45,129	818.6	55.13
53	73,593	1647.9	44.66
54	68,936	1785.9	38.60
55	29,555	1125.9	26.25
56	29,330	942.5	31.12
57	10,575	288.5	36.65
58	23,939	687.9	34.80
59	36,337	1093.8	33.22
1960	31,000*	—	—
		Nova Scotian Banks	
1951	151,679	6922.8	21.91
52	83,933	5013.9	16.74
53	29,606	1837.7	16.11
54	46,065	1899.5	24.25
55	20,569	1099.9	18.70
56	35,963	1460.7	24.62
57	46,519	1895.6	24.54
58	67,830	2555.8	26.54
59	54,448	2391.2	22.77
1960	71,000*	—	—
		Gulf of Maine	
1951	68,213	9814.8	8.95
52	47,128	6042.1	7.80
53	37,017	4459.8	8.30
54	28,633	3858.9	7.42
55	30,675	3089.1	9.93
56	31,720	3266.7	9.71
57	36,306	3862.3	9.40
58	35,725	3671.6	9.73
59	34,414	3599.8	9.56
1960	30,000	—	—

*Preliminary estimate—data for January-September 1960.

ch and fishing effort, length composition, and asite incidence collected since the start of the hery in 1935 are being analyzed to delineate smallest redfish groups that can be treated as its in population dynamics studies.

Field work was continued on the inshore ck of redfish at Eastport, Maine. Recap- e of many tagged fish at the tagging site has mitted continuing observations of the effect tagging on the growth rate. Other studies the natural mortality of tagged fish and esti- tion of population size are also in progress. pers on these subjects were presented at the NAF Marking Symposium in May 1961.

Yellowtail Flounder (*Limanda ferruginea*) (Storer)

The Fishery. Landings of yellowtail under in recent years have increased greatly. e composition studies show that much of the rease is due to large year-classes spawned in 55 and 1956. In addition, a strong year-class s spawned in 1958 and fish from it entered landings in 1960. These three strong year- sses will help to maintain yellowtail produc- n at a high level during 1961.

TABLE 4. Trends in the U.S. yellowtail fishery.

Year	Landings (thousands of pounds)
1951	18,430
52	16,987
53	13,716
54	12,763
55	14,373
56	14,643
57	22,445
58	33,325
59	29,000
1960	31,000

Research. Research during the past year consisted of yellowtail stock identification, ative abundance, and age and growth rate dies. For stock identification, an analysis recoveries from 1955 and 1957 tagging was d. In addition, information on exploited owtail groups was gained from meristic nts and from studies of the incidence of para- infestation. Three yellowtail groups were ntified. For relative abundance studies, av- ge landings per day were computed for yellow- tail trips from three fishing grounds. Yellowtail abundance was high in the early 1940's, dropped in the late 1940's and early 1950's, and rose in recent years. For age and growth studies, scales collected from commercial and experimental catches from 1957 to 1960 were used. Separate growth and age composition studies were made for each identified yellowtail group. These studies, while incomplete, show that growth rate varies according to area of catch. They have also provided information on strong and weak year-classes.

Sea Scallop (*Placopecten magellanicus* (Gmelin))

The Fishery. U.S. landings of sea scallop meats from Subarea 5 in 1960 were the highest in the history of the fishery even though fishing effort declined somewhat. This resulted from the extraordinary abundance of the year-class recruited to the fishery during 1959. On certain grounds the fishermen were able to catch as many sea scallops as they could shuck in a day with only a few hours dredging.

Research. One survey cruise was made to collect data on abundance of the fishable stock and strength of the pre-recruit year-classes. Data were also collected for the calculation of growth and mortality rates to be used in population dynamics studies.

Data on the amount and size distribution of the landings, as well as the number of days spent on the grounds continue to be collected at all ports of landing. Copies of the catch and effort statistics compiled by area of capture have been sent monthly to Commission headquarters. A critical comparison of these data with quantitative abundance indices collected from research vessels has shown that the raw landings per day figure cannot be used as a reliable index of abundance in this fishery. There is an upper limit to the number of scallops which the crew can shuck per day. Once the catch in numbers reaches this limit, the amount of the landings per day spent on the grounds depends strictly on the average size of scallop being shucked. On one ground, the average weight of the landings per day spent on the ground rose from 2200 pounds in June of 1959 to 3600 pounds in May of 1960. Research vessel samples showed that the population was

TABLE 8. Trends in the Sea Scallop Fishery.

Year	Landings (millions of pounds)	Days Fished	Average Landings per day (pounds)
1951	12.4	7,626	1,626
52	12.1	7,742	1,563
53	16.3	10,031	1,625
54	15.5	9,343	1,659
55	18.3	11,619	1,575
56	17.5	12,246	1,429
57	17.3	10,500	1,651
58	14.4	8,775	1,637
59	18.7	8,556	2,189
1960	21.9	8,039	2,725

reduced to one-sixth of its previous abundance in one year on that ground. The 63-percent increase in the landings per day was the result of growth.

Studies of the cycle of gametogenesis have shown that sexual products are rapidly regenerated during winter and early spring, but that the animals remain fully ripe for almost six months before spawning in the fall. Data on the seasonal and areal variation in the length-weight ratio have been collected and are being analyzed.

Industrial Fishery.

The reduction of non-food trawl fish to meal and oil was almost completely stopped in September 1959 and was not resumed in 1960. Market sampling, of course, was terminated in the absence of landings. Previous data have been analyzed and the 1959 species composition report completed.

An analysis of the quantities and sizes of young haddock and other commercially important groundfish species taken by the industrial trawl fishery and its sister industry, the silver hake fishery, has been made. This study indicates that the small mesh industrial and silver hake fisheries may seriously influence the potential recruitment of haddock and other groundfish species. This research is continuing.

One of the important species in the industrial fishery is the red hake (*Urophycis chuss* Walb.) Some preliminary studies were initiated to determine the age and growth. Various structures were examined to determine which might be most suitable for age reading. The otoliths appear to be generally unsuitable, but the scales show some promise.

Benthos Investigations.

A study of relationships between bottom sediments, benthic invertebrate fauna, and the foods of groundfish is continuing. Results of an inventory of Georges Bank benthic fauna have revealed that pronounced differences in the haddock's diet from one locality to another are due largely to differences in available foods. Also, marked variations in species composition and quantities of benthic organisms were found to be correlated with sediment type. In this regard, benthic organisms were much more abundant in substrates composed of gravels and coarse sand than in fine-grained sediments.

Bottom sediments of Browns Bank and the southern Gulf of Maine are the subject of a report now in preparation. Analysis of sediment samples from these areas indicates that gravels and coarse sands are the predominant component on Browns Bank, whereas in the southern Gulf, silts and clay are most prevalent.

Evaluation of Mesh Regulation.

Studies of the effect of the mesh regulation in the Georges Bank haddock fishery continue. They show that the regulation has been beneficial in reducing the proportion of discards of small fish and in increasing the relative catch of larger fish. This results in easier handling of the catch

on board the vessels and increases the efficiency of processing operations ashore.

Our principal concern is to demonstrate an increase in yield per recruit. Studies of this problem involve a comparison of the total yields of year-classes over their fishable life span. Year-classes after mesh change should yield more pounds of fish than year-classes of the same initial size before mesh change. Evaluation of regulation on this basis requires an accurate measure of the initial strengths of year-classes before and after regulation. Although values are available for many year-classes prior to regulation and values are available for post-regulation year-classes, the post-regulation values are not comparable to those for pre-regulation year-classes. To date, it has not been possible to find an entirely satisfactory method of adjusting the new values to make them comparable with the early ones.

As more large year-classes pass through the fishery more data will become available for this study. As data accumulate and more effort is devoted to developing new methods of evaluation, a more firm demonstration of the increase in yield per recruit should emerge.

B. BY DEAN F. BUMPUS

WOODS HOLE OCEANOGRAPHIC INSTITUTION, WOODS HOLE, MASSACHUSETTS

Hydrographic Research by the U.S.A. in the Convention Area was carried out by four agencies during 1960; the U.S. Coast Guard, U.S. Coast and Geodetic Survey, the Bureau of Commercial Fisheries, and the Woods Hole Oceanographic Institution.

A. The U.S. Coast Guard, as the agency operating the International Ice Patrol, examined the temperature and salinity distribution in four network surveys in the Grand Banks region. The first survey, 1-17 April, in addition to covering the southern and eastern slopes of the Grand Banks extended south to Latitude 37°30'N. in order to cooperate with the "Gulf Stream '60' " survey (see below). The second survey, 1-9 May, covered the eastern and northeastern slopes of the Grand Banks. This was followed by an evaluation of the wind effect on iceberg movements. Parachute drogues were employed during this phase of the study. The third survey, 3-6 June, covered the Bonavista triangle and the fourth survey, 17 June-1 July, covered the area immediately seaward of the southern and eastern slopes of the Grand Banks from just westward of the Tail of the Banks to the latitude of Flemish Cap. A post-season cruise, 5-13 July, included occupation of the Bonavista triangle and a section across the Labrador Sea from South Wolf Island, Labrador to off Cape Farewell, Greenland.

The report *in toto* will be published in U.S. Coast Guard Bulletin No. 46.

B. The U.S. Coast and Geodetic Survey set-up a bubbler-type tide gauge on Texas Tower L3 (on Nantucket Shoals) and ran 100 hours of simultaneous current observations at three depths at each of three buoys in the same general area. One hundred hours of current measurements were made off Point Judith.

C. The Bureau of Commercial Fisheries has collected a limited amount of temperature (bathythermograph) data in Subarea 5 in the course of the second cruise of the *Delaware* and along the coast of Maine during the latter part of the year through the efforts of the Biological Laboratory at Boothbay Harbor, Maine.

D. The twelve U.S.C.G. lightship stations from Maine to Georgia, equipped at the end of 1955 by the Woods Hole Oceanographic Institution under contract with the Fish and Wildlife Service, as observation posts to collect surface temperature and salinity observations daily, bathythermograms daily, and bottom water samples weekly, have continued in operation. Several of the lightships have also released drift bottles daily.

E. A cooperative study including the Fisheries Research Board of Canada, the Bureau of Commercial Fisheries, the Weather Bureau At-

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Some Observations on Rearing Blue Crab Larvae[1]

ABSTRACT

Foods tested were found inadequate for rearing the zoeae of the blue crab, *Callinectes sapidus*. Microorganisms associated with these foods increased larval mortality. This was controlled to some extent by addition of Terramycin HCl to rearing bowls. Large differences in survival were found between zoeae from different parents hatched and reared under identical conditions.

Blue crabs, *Callinectes sapidus*, were successfully reared from larvae to the adult form by Costlow, et al. (1959:222–3) and by Costlow and Bookout (1959:373–96). Survival, however, was low, ranging from 1 to 8 percent. Studies to determine the effects of environmental factors on larval survival require an abundant supply of healthy, active zoeae for detailed experiments. Since an adequate food for early zoeal stages is a major requirement for increased survival, a number of organisms and organic materials were tested. Those with no apparent utilization as food included cultures of 11 genera of phytoplankton (*Gymnodinium*, *Amphidinium*, *Chlamydomonas*, *Platymonas*, *Isochrysis*, *Monochrysis*, *Prorocentrum*, *Nitzschia*, *Carteria*, *Chlorella*, and *Dunaliella*), animal tissues (beef, beef liver, shrimp, clam, and mussel), and eggs from several unidentified species of fish and barnacles. Two foods, *Arbacia punctulata* eggs and *Artemia salina* nauplii, used by Costlow and his co-workers were tested separately and in combination. Repeated experiments with larvae in the first three zoeal stages demonstrated feeding on *Arbacia* eggs, but not on *Artemia* nauplii.

Microorganisms (protozoans, fungi, and bacteria) associated with the foods used in the above experiments adhered to and often weighted down or entangled the zoeae. Two dyes, having fungicidal properties, and four antibiotics were tested in an effort to eliminate these organisms and increase zoeal survival. The dyes, malachite green and Victoria blue R, were toxic to the zoeae at low concentrations. Chloromycetin, in the dose range of 25 to 100 mg/l, produced a slight increase in zoeal survival for the first three days, but an adverse effect by the end of seven days. No effect was observed with Penicillin G in concentrations of 50,000 to 200,000 units/l. A difference in survival was observed when Terramycin HCl was used. At concentrations of 15, 30, 45, and 60 mg/l, survival was 76, 71, 83, and 58 percent, respectively, at four days as opposed to 55 percent for the controls, and on the fourteenth day was 16, 20, 23, and 18 percent, respectively, as opposed to 3 percent for the untreated control group. Preliminary experiments with Aureomycin produced results similar to those obtained with Terramycin. In all studies, greatest mortality occurred at the time of molting.

During the feeding experiments, it was found that considerable variation in survival occurred between zoeae from different parents. To further observe these differences, egg masses from two groups of five crabs each were hatched and reared under identical experimental conditions. All zoeae were fed on a combination diet of *Arbacia* eggs and *Artemia* nauplii and were kept at a temperature of 24°C. and a salinity of 25‰. Curves representing

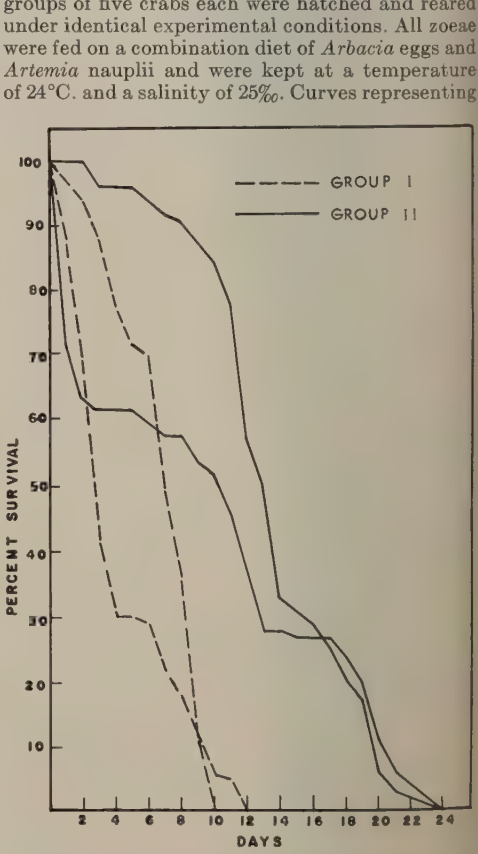

Fig. 1.—Extremes of survival for zoeae of the blue crab, *Callinectes sapidus*, from two experimental groups.

[1] Studies performed by the Oyster Institute of North America under contract to the U. S. Bureau of Commercial Fisheries, Fish and Wildlife Service.

tremes of survival for zoeae from each group e shown in Fig. 1. For Group I zoeae (broken es), total survival varied from 30 to 78 percent the fourth day. All were dead in 12 days and molting occurred. Some Group II zoeae (solid es), tested under similar conditions, survived days. Greatest survival difference, about 34 rcent, occurred at approximately six days. A rge number of second stage zoeae (321 or 47 rcent) began to appear on the seventh day, and third stage zoeae appeared, starting on the eventh day. The reason for these differences in rvival is unknown.

These preliminary studies indicate that al- ough zoeal survival may be enhanced by the ldition of certain antibiotics to rearing bowls, e lack of a completely adequate, readily available food source points out the need for additional studies on this phase of investigation.

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